REPORT RESUMES

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STANDARDS OF TELEVISION TRANSMISSION. FACTORS AFFECTING
MICROWAVE RELAY AND CLOSED-CIRCUIT TRANSMISSION OF
EDUCATIONAL MATERIALS.
BY- BRONSON, VERNON AND OTHERS
NATIONAL ASSN. OF EDUCATIONAL BROADCASTERS
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TECHNICAL STANDARDS FOR EDUCATIONAL TELEVISION TRANSMISSION WERE DISCUSSED. SUBJECTS COVERED WERE (1) THE LIMITATIONS AND POTENTIAL OF PRESENT TELEVISION EQUIPMENT, (2) AN INTERCONNECTION NETWORK FOR EDUCATIONAL INSTITUTIONS, (3) TECHNICAL FLEXIBILITY AND VARIOUS EDUCATIONAL NEEDS, (4) FREQUENCY BANDS AVAILABLE FOR THE INTERCONNECTION OF EDUCATIONAL TELEVISION SYSTEMS, AND (5) APPLICATION OF A COMPUTER PROGRAM FOR SELECTION OF MICROWAVE CHANNELS. THE CAPABILITY EXISTS FOR BUILDING A TRANSMISSION SYSTEM THAT WOULD TRANSMIT A TELEVISION PICTURE OF A MUCH HIGHER QUALITY THAN IS POSSIBLE WITH CURRENT BROADCAST STANDARDS. (AW)

U. S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
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STANDARDS OF TELEVISION TRANSMISSION

Factors Affecting Microwave Relay and Closed-Circuit Transmission of Educational Materials

NATIONAL ASSOCIATION OF
EDUCATIONAL BROADCASTERS

June, 1964

ED003142

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NATIONAL ASSOCIATION OF EDUCATIONAL BROADCASTERS
1346 Connecticut Avenue, NW
Washington, D. C. 20036

PROJECT DIRECTOR: Vernon Bronson

ASSOCIATE DIRECTOR: James A. Fellows

ENGINEERING CONSULTANT: John J. Renner

TECHNICAL EDITOR: William J. Kessler

REPORT COMPILED AND EDITED BY: Vernon Bronson and
James A. Fellows

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To The Reader

The material in this report has been prepared in such form that both experienced educators and experienced engineers can benefit from its conclusions and its contents. Although much of the basic information is technical, the importance of the educational implications of these data are such that individuals concerned with the use and expansion of television for education ought to grasp the fundamentals upon which the report rests.

The body of the report has been prepared so that a person with a minimum technical background can read it easily and understand the essential problems. For those who need to begin by understanding basic concepts of television engineering, the material in Appendix A will be helpful. For those engineers who would like to go beyond the major part of this report and study certain matters in detail, Appendices B, C, and D should be consulted.

The educator who reads this report must understand at the beginning that technical information has been included only to provide a more satisfactory basis for understanding the factors that need consideration in the development of a single television system and in providing facilities for sharing resources with other television systems at other educational institutions.

When it is understood that errors made because of the lack of information during the initial planning for television facilities may cost thousands of dollar and severely limit the uses and future expansion of the system, the few hours it may take to study the contents of this report will be considered a worthwhile investment.

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Introduction

Few people will believe that it is possible to produce a television picture fully comparable to that produced with a high quality motion picture film. Their orientation to television has often been to small screens, standard broadcast pictures, average receivers, and poor viewing conditions. Having grown up with television and experienced its early technical difficulties, a steady picture is widely accepted as satisfactory, and thought is seldom given to any possible improvement.

The message of this report is that the television system with which we are most familiar uses but one of many possible standards, and for particular needs appropriate technical standards should be identified and established. In other words, requirements of educational need in a given circumstance should determine the kind of television system which is established; a system should not be built so as to limit the variety of services which it might be able to provide.

The system of television broadcasting which is known to all of us is a compromise based largely on the need to provide a home broadcast service with reasonable picture quality at an economical price. But this is only one of many possible television systems. Educational needs should be considered in the light of technical standards far superior to broadcast television, or in some specialized situations in terms of less rigid requirements.

Apart from the consideration of different technical standards, emphasis must also be given to the improvement of facilities which already exist. The possibilities for improving these facilities and for the design of new and higher quality television installations are important prefaces to the widespread use of television for direct instruction and other educational purposes.

Throughout this report "good" television picture, "good" microwave networks, and "good" performance are discussed. What makes a "good" television picture is definitely affected by the use that is being made of the picture. A picture that appears to be good, (i.e., possesses acceptable resolution and contrast) on a portable receiver carried to the beach, would seldom be considered good if it were to appear on a monitor in a medical classroom where a student would be expected to learn from the picture he sees.

In order to achieve the maximum resolution and contrast possible within any television standard, it is necessary to secure optimum performance from each piece of equipment. This might seem to be obvious, but concern with the utilization of television often obscures such obvious operational aspects. It is like teaching literature with pages ripped from the books, or teaching biology with a poorly focused microscope. An excellent example of this situation exists in the present use of broadcast equipment.

The picture viewable on a home receiver seldom represents the full capability of the U.S. broadcast system. While there are certain equipment limitations, which exist largely because of the economics of a competitive market, it is often the obvious and simple adjustments that restrict the retention of the fullest possible quality throughout the broadcast system. Antennas may not be properly oriented, cables may be mis-matched, the home receiver may not be properly adjusted, station transmitters may be out of adjustment, or amplifiers may have drifted out of adjustment. When the unnoticed or ignored results of aging, weather and dust are added, the gap between actual and possible performance widens further.

A further element of performance that is often overlooked is concerned with the initial purchase of equipment. Many studies have been made on the cost-quality relationship in television equipment, and all have shown that both "cheap" and "expensive" equipment may actually cost substantially the same over their useful life period. The important difference, which is often overlooked, is that the so-called "expensive" equipment will usually provide better performance over a longer useful life, with less maintenance while the performance of the "cheap" equipment will often degrade rapidly, even if the equipment is maintained properly. This factor is particularly important where funds for maintenance are scarce.

In addition to facilities at a single institution, we must consider a broader problem. Until recently, educational television has largely been concerned with single broadcast stations or in-school closed-circuit systems. However, as more and more educational television systems are established, the usefulness of inter-connecting them in order to share technical and personnel resources is becoming more and more apparent. Because the ultimate utilization of television for educational purposes must encompass the exchange of ideas and information among many points, it is important to consider interconnection facilities not only for schools, but also for libraries, research laboratories, technical centers, and cultural facilities.

There are a number of methods to accomplish this exchange, but long-range interconnection which provides for maximum flexibility and efficiency and reasonable economy can best be provided by microwave. Interconnection systems for this purpose must be provided by either a common carrier or a privately owned system. In either case the basic facilities should take advantage of the technical characteristics of microwave frequencies.

A microwave network is actually a chain of relay stations. The purpose of the network is to relay information in the form of electrical signals with minimum degradation of the signal quality. In standard television broadcasting the object of transmitting a signal is to cover simultaneously as many viewing locations as possible, but in microwave networking the goal is to provide transmission of the signal to a specific receiving station, which will then pass along the signal to the next in line.

Several recent* actions by the Federal Communications Commission have created concern and prompted action toward a broad, long-range study of microwave needs. Because microwave channels are not reserved and regulated in the same manner as broadcast channels, this study has taken a somewhat different form from related studies concerned with standard broadcast frequencies.** A study of microwave networking and of microwave channel availibility as they are related to the needs of education requires recognition of three fundamental facts:

(1) Television is a system of compromises.

(2) Television standards may be altered to meet specific needs.

(3) An educational television interconnection network must be capable of handling the maximum expected requirements.

1. Television is a System of Compromises

Television is a complex, inter-related process involving a number of techniques and different devices. Many technical and operation compromises have been made for practical reasons. If they had not been made, television would not be available in the low-cost and multiple channel brodcast form that is known today.

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*Federal Communications Commission, Notice of Proposed Rule Making, Docket No. 14721 and Docket No. 14729, July 20, 1962.

**NAEB and USOE, A Report of a Study of Nationwide Assignments of Television Channels for Maximum Service and Efficiency by the Use of Electronic Digital Computer Methods, 1962; and NAEB and USOE, UHF Television Channel Assignment Plan, October, 1963.

As is often the case, however, certain of the compromises have been tailored to fit specific applications or situations. As a result, certain television systems are acceptable for the situations to which they have been tailored, but are often unacceptable for other situations. Attempts to adapt such systems to other situations often lose sight of this fact, and compromises inherent in a particular television system become the controlling factors in the use of that system for different needs. This trend has been noticed in educational television, and will be discussed in more detail in subsequent chapters.

2. Television Standards May be Altered to Meet Specific Needs

Examples of specific situations, to which specific television systems have been tailored, range from the observation of a simple industrial process to theatre projection to space flight. In each case, a particular form of television has been developed to satisfy a particular need. The possibility of altering characteristics to match specific needs should be utilized to provide a wide range of flexibility in the possible use of television, but a certain amount of planning is necessary to insure that short range steps do not inhibit long range goals.

To achieve maximum benefit from television with a minimum of cost and complexity, it is essential to understand the relationship between the technical characteristics that affect television transmission and the requirements that affect satisfactory application in each area of need. With proper attention to the selection of optimum characteristics, and in particular the proper match between technical characteristics used for transmission and the subjective viewing results to be achieved, a wide variety of needs can be satisfied with the same transmission facilities.

One of the functions of this report is to establish the relationship between subjective needs and required transmission characteristics, and to develop a technical basis for evaluating educational needs in terms of what can be provided technically. In this way, a major step will be taken toward establishing the basis for meeting educational needs through proper equipment design, through proper system engineering, and through the provision of appropriate regulations and tariffs.

3. An Educational Television Interconnection Network Must be Capable of Handling the Maximum Expected Requirements

Any electronic communication system, whether a microwave network or a television broadcast system, must be designed to transmit a specific amount of electronic information; it can handle less, but the limitation on its potential use is its maximum capacity. If sufficient technical capacity exists, the actual content of the information is not relevant at this point.

A microwave system must be designed with enough capacity to handle the electronic signals that contain the subjective information, and must relay a signal of the complexity of the television signal over the required transmission distance. Once a microwave system is designed with a capability for carrying a television signal of a given complexity, it automatically has the capability for accommodating signals of lesser complexity and for handling a combination of signals that collectively do not require more capacity than is required for the television signal.

Of particular importance is the fact that microwave equipment capable of satisfying the requirement for relaying a signal of normal broadcast quality over large distances can be so designed and used that it will provide greater capacity over shorter distances without significant increase in cost. There exists, technically, the capability for building a transmission system capable of transmitting a television picture of much higher quality than that possible within the broadcast standards.

The implications of these technical conclusions relate to regulatory procedures in which the FCC is involved. The analysis of educational need and the detailed report of microwave inter-connection characteristics included here provide information that will be helpful in answering a number of questions that pertain to various aspects of microwave frequency allocations.

Finally, the NAEB has applied the procedures used in allocation studies of the UHF television frequencies to a study of microwave frequency usage. This pioneer effort to develop a systematic method of cataloguing and using data required for such determinations completes the study. As the concluding part of the report, it places emphasis on the expanding interest among educational institutions to interconnect their physical plants in order that talent and resources of all types and varieties will not be limited to a single institution or locality.

I

The Limitations and Potential of Present Television Equipment

EXISTING LINE STANDARDS

The television equipment that is available today operates with a variety of line standards. It is actually available with line standards ranging from 200 to 1300 scan lines, but only a few specific standards have been used to the degree that equipment for them is easily available. These are listed in Table I, along with an example of their present use and their approximate video bandwidth. All use the 30 picture per second frame rate and 2 to 1 interlace.

The 525 line system used in the U. S. for broadcast television is based on a particular set of standards which is the product of many compromises. This is not the only system, and it is by no means the most economical system for all applications. The U. S. broadcast standards represent compromises based on the particular requirement of television reception in the home. Other standards have been developed in other countries (see Figure 1) and represent other opinions as to what is most appropriate for home reception.

In the United States (see Table 1 and Figure 2), the 675 line systems have been employed for the transmission of written information in banks, for information retrieval in libraries, and for medical training. The 875 line standard is employed in the military where detailed observation of objects from a long camera viewing range is required. The 1029 line system is somewhat experimental but has been used in medical and scientific process observation.

TABLE I

TELEVISION LINE STANDARDS FOR WHICH EQUIPMENT IS READILY AVAILABLE

*Line Standard	Example of Common Usage In The U. S.	Approximate Video Bandwidth (Mcs)
525	Broadcast	4.2
675	Medical Training	6
750	Theater Display	9
875	Military	11
1029	Medical, Scientific	16

*30 frames per second; 2 to 1 interlace.

Non-compatibility between different systems has been a block to the full exchange of television programs and data, and cases exist when the need for high resolution has been foregone so that materials can be shared. These are examples of situations where an existing television system has been allowed to control the use and the usefulness of television. Such occurrences are unfortunate because it is fully possible to utilize high resolution standards to meet particular needs and to transform the information to a compatible standard only if needed for exchange or record.

Not all elements of the television system are at the same state of development. The following sections will discuss the important details of each device and report on the capabilities of each, at its current state of development.

TELEVISION CAMERAS

Synchronization

The purpose of synchronization* is to provide alignment of the picture elements at the receiver that are in agreement with the picture developed in the camera. To achieve high quality alignment it is necessary to send a special synchronization signal along as part of the transmitted signal. This provides a reference point for proper alignment of the picture and permits a "locking" or absolute synchronization of the received signal with the signal originating in the camera. Some systems provide a less absolute "sync" by using the power line frequency as a substitute for the vertical sync-pulse. These systems are less expensive, and do not provide a complete synchronizing signal that is characteristic of a standard synchronizing generator.

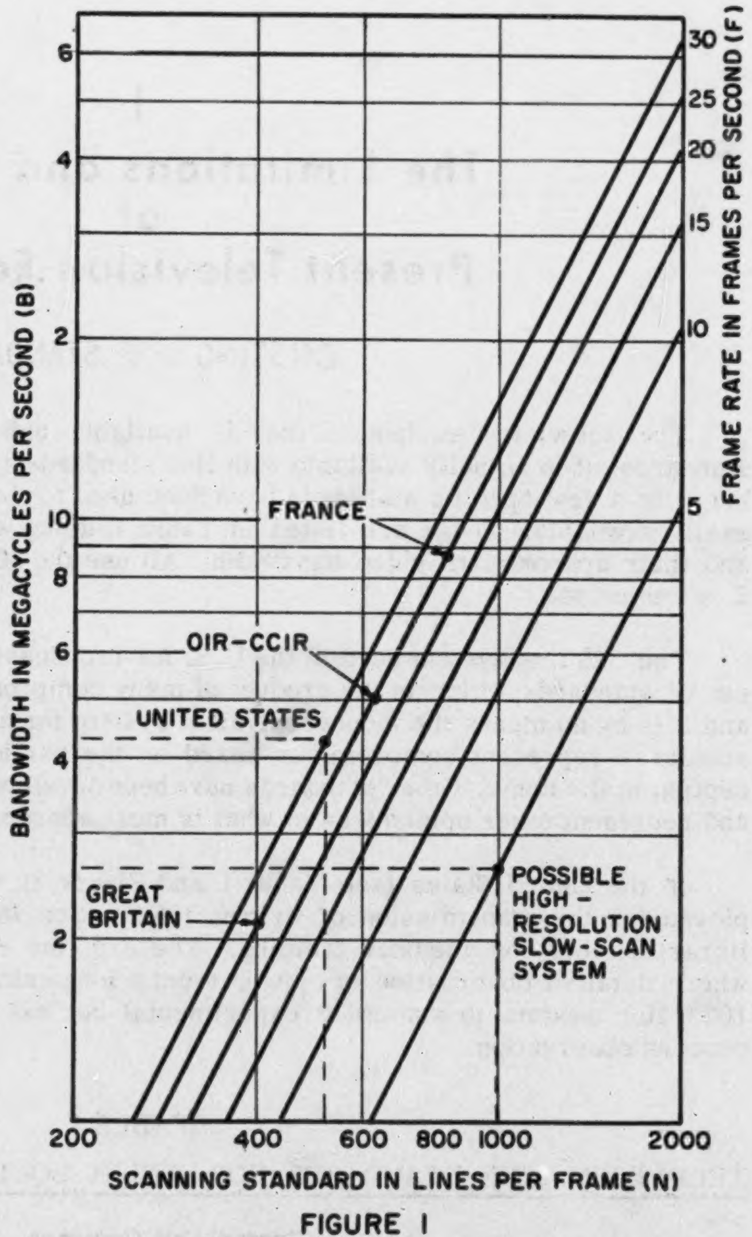

FIGURE I
BANDWIDTH REQUIRED FOR HORIZONTAL DETAIL TO EQUAL VERTICAL DETAIL

The FCC has prescribed strict limitations on the stability and form of the synchronizing pattern used in the broadcast system. The prescribed pattern must be used in all broadcast television programs, but use of this pattern is not necessarily required in non-broadcast transmission. Consequently, some closed-circuit systems utilize industrial synchronization, which may be an integral part of the camera, and is thus less expensive. However, there is a development in broadcast type vidicon cameras that also uses camera-contained sync generators that are built to E.I.A. standards.

Broadcast synchronization systems generate a 2 to 1 interlace pattern generally referred to as positive interlace. Many non-broadcast systems utilize what is often referred to as a "random" interlace. Positive and "random" interlace have several differences, but the primary distinction is in the manner by which the vertical scanning frequency is derived. In positive interlace the vertical scanning frequency is a submultiple of the

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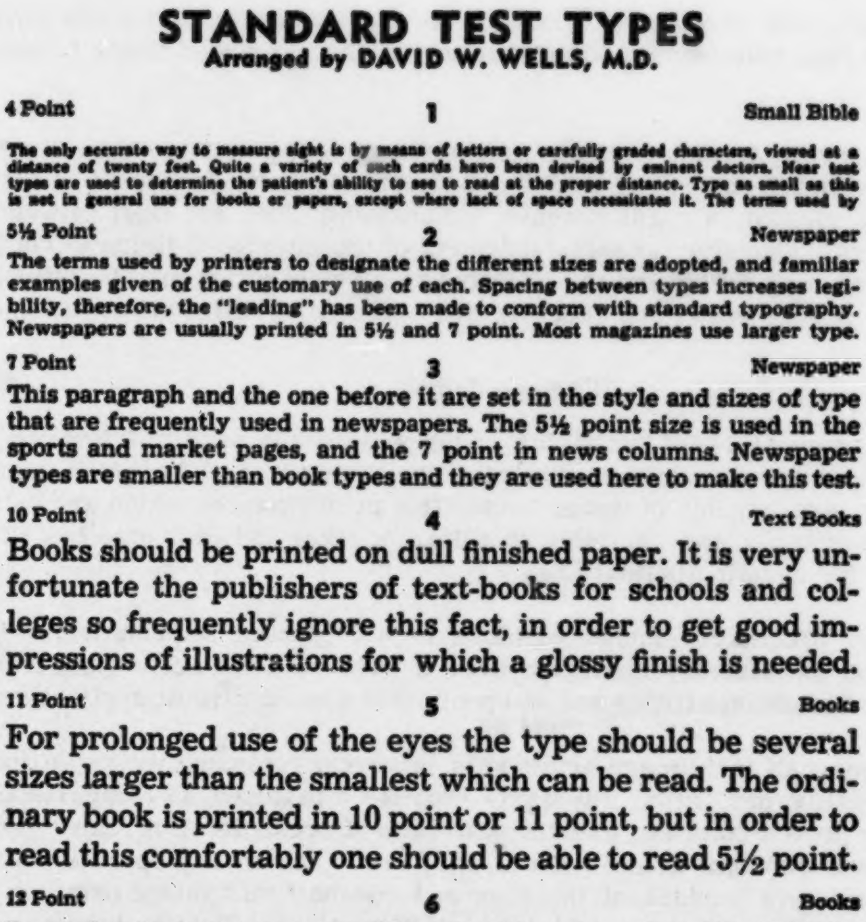
*See Appendix A, Page 47 for further information on scanning and synchronization.



STANDARD TEST TYPES

Arranged by DAVID W. WELLS, M.D.

4 Point **1** **Small Bible**

The only accurate way to measure sight is by means of letters or carefully graded characters, viewed at a distance of twenty feet. Quite a variety of such cards have been devised by eminent doctors. Near test types are used to determine the patient's ability to see to read at the proper distance. Type as small as this is not in general use for books or papers, except where lack of space necessitates it. The terms used by

5½ Point **2** **Newspaper**

The terms used by printers to designate the different sizes are adopted, and familiar examples given of the customary use of each. Spacing between types increases legibility, therefore, the "leading" has been made to conform with standard typography. Newspapers are usually printed in 5½ and 7 point. Most magazines use larger type.

7 Point **3** **Newspaper**

This paragraph and the one before it are set in the style and sizes of type that are frequently used in newspapers. The 5½ point size is used in the sports and market pages, and the 7 point in news columns. Newspaper types are smaller than book types and they are used here to make this test.

10 Point **4** **Text Books**

Books should be printed on dull finished paper. It is very unfortunate the publishers of text-books for schools and colleges so frequently ignore this fact, in order to get good impressions of illustrations for which a glossy finish is needed.

11 Point **5** **Books**

For prolonged use of the eyes the type should be several sizes larger than the smallest which can be read. The ordinary book is printed in 10 point or 11 point, but in order to read this comfortably one should be able to read 5½ point.

12 Point **6** **Books**

In order to get a proper illumination one should sit with his back to the light. Objects are seen by the light which goes from the object to the eye, not from the eye to the object. This precaution is quite commonly neglected.

18 Point **7** **Children's Books**

Children should be allowed to use only such books as are printed in large, clear type, and excessive reading forbidden.

American Optical
COMPANY

MINIMUM TYPE SIZES WHICH CAN BE ADEQUATELY REPRODUCED FROM AN 8½" BY 11" PAGE

SYSTEM	SCANNING STANDARD IN LINES PER FRAME	MINIMUM TYPE SIZE	MAXIMUM WORDS PER PAGE
British	405	45 point	60
U. S.	525	35	100
European	625	30	140
French	819	22	250
	910	20	300
	1000	18	360
	1300	14	620
	1500	12 (textbook)	840
	2000	9 (newspaper)	1500

FIGURE 2

horizontal synchronization frequency. Thus the vertical and horizontal scans bear a fixed and virtually unvarying relationship to each other and the interlaced fields fit exactly between each other.

The vertical scanning frequency in the "random" interlace pattern may be derived from the 60 cycle power line frequency. Since the horizontal scanning frequency is usually developed by another method, a rigid scanning relationship does not exist between the two scanning frequencies. Therefore, exact placement of the interlaced fields is not probable and visual flickering may result and the effective picture definition may be reduced. This is especially likely if the camera and receiver are operated on different power lines.

Camera Tubes

The two most common types of image pick-up tubes currently used in television cameras are the image orthicon and the vidicon. While the two are entirely different in construction and operation, they are capable of image translation performances which are comparable in many ways. Both types are available in different sizes and each size has advantages particularly useful for certain applications.

The three-inch (diameter) image orthicon is widely used because it provides good quality pictures and satisfactory operation over a wide range of scene light levels. It is used extensively in broadcast studios and in specialized closed-circuit applications.

The four and one-half inch image orthicon is, however, replacing the three-inch image orthicon in high quality production situations because it features, in comparison with the three-inch tube, improved contrast, greater definition of scene detail (greater resolution), greater freedom from random "noise" effects, and greater day-to-day operational stability. The larger photoemissive surface of the four and one-half inch image orthicon makes it slightly less sensitive than the three-inch tube, so higher scene lighting levels may be required to obtain maximum performance.

The vidicon was initially inferior to the image orthicon, but recent technological advances have created new vidicons which in some instances are comparable in performance with the image orthicon. The development that was responsible for these vidicons was a new photoconductive material which exhibited improved sensitivity and decreased lag.*

The vidicon is available in one-half inch, one inch, and one and one-half inch diameters. The one-half inch tube does not provide adequate resolution for all television purposes because of its small photocathode size, but it is widely used in specialized applications where the small overall tube size is desirable. The one-inch tube is the most common and is widely used in closed-circuit cameras and in film chain cameras. The resolution and contrast capabilities of this tube are comparable to that of the image orthicon, but the vidicon is not so sensitive. The one and one-half inch vidicon is a recent development and has a significantly greater resolution capability than the one-inch vidicon or the three-inch image orthicon, but, again, the increased photocathode size results in less sensitivity and greater lag. Efforts are being made to improve the sensitivity of these larger tubes, and some progress has been made in decreasing undesirable lag effects.

In general, both the image orthicon and the vidicon are capable of providing approximately 1500 lines resolution. Different versions of each exist and each version has different characteristics, but at least one version of each tube type is capable of meeting the resolution demands likely to be placed on the television camera in the near future. The sensitivity requirements can be met with the existing tube types. The contrast capabilities of both types are good.

---

*Lag, in a vidicon, refers to the retention of electron charge patterns corresponding to scene images on the photocathode surface for undesirably long periods.

For educational purposes, the camera and camera tube type to be used in a specific situation should be selected to meet the requirements of the situation rather than adjusting the situation requirements to conform with the camera capabilities. Insofar as an individual situation requires an image tube with long tube life, utility and economy, the vidicon has the advantage. When high quality production is the primary consideration, the image orthicon camera should be considered.

RECEIVERS AND MONITORS

A monitor is a special type of receiver used at a studio or transmitter location to "monitor," that is "examine," the electronic television signal produced in the camera chain. Its purpose is to insure that the picture quality is good at the time it is sent to the transmitter. A monitor differs from a normal television receiver used in the home in that it receives the signal before transmission rather than after transmission. Since it is used to examine the signal sent to the transmitter, it is designed to provide the full quality available from the camera. This is actually better than the quality possible after transmission from a broadcast transmitter, but it is not necessarily better than the signal that can be transmitted over a microwave relay network.

The broadcast picture quality is limited by the bandwidth available for such transmission – a total of 6 Mc for both picture and sound. The quality available from a camera is that provided by a channel bandwidth in the order of 8 Mc for the picture alone.

The normal home receiver is limited to the maximum quality obtainable in a 6 Mc broadcast television channel. As a practical matter, the problem of containing the video and sound signals within this bandwidth is so severe that only the best available receivers can achieve or approach the full potential quality of broadcast transmitters.

Broadcast transmitters are required to achieve a high degree of the available performance capability within the 6 Mc channel limitation, and their transmitters must comply with the rigid requirements of the FCC.

On the other hand, the manufacturer of home receivers is faced only with the competitive problem of doing as well or better than his competition. The result is that the average home receiver does not realize the full quality potential of the transmitted signal. Poor receivers severely limit the quality, and the best receivers available for home use only approach full potential quality. The reason for the receiver restriction on quality is the difficulty of achieving a design – at reasonable price – that will fully exploit the capability of the broadcast signal. The problem of maintaining the design quality of a home receiver is still another factor that tends to accentuate an already undesirable situation.

With the present state-of-the-art, manufacturers ought to be able to produce a monitor costing no more than a good receiver, since the monitor does not have to cope with the problem of separating the sound from the picture. Current lack of demand for high quality monitors, however, reduces the likelihood of comparable costs at the present time. Nevertheless, in any educational television system it is important that the receiving capabilities be matched as closely as possible to the transmitting capabilities. Usually the cost of receivers is such a small part of the overall cost that this should be financially feasible in any system.

TELEVISION PROJECTION SYSTEMS

Two projection methods are currently in use. One is an elaborate projection system employing high light levels for theater size screens and capable of projecting color images. The other is a smaller system using Schmidtt optics in which the image from a special high intensity picture tube is enlarged.

Two disadvantages of the smaller projection systems are the low room light levels in which they must be shown and the geometric distortion of the projected pictures. They are limited to a greater degree by the optics than by the characteristics of the received television signal. They can be adjusted to provide an average quality picture, but will generally fall short of perfection due to geometric distortion, and low screen light level.

Projection systems impose a severe requirement on a television transmission system in order to allow for the optical degradation of the projected image and to insure that the additive factors of optical degradation do not become excessive. A further requirement for improved performance results from the fact that a normal receiver or monitor is normally viewed at distances of approximately five times the picture height, whereas a large screen may be viewed at distances that have a much lower viewing distance to picture height ratio. At such close distances it is possible for the eye to resolve more detail. If a viewer at a short distance from the projection screen is to avoid annoying viewing effects it is necessary that the television picture itself have greater resolution. For distant viewing, i.e., at distances greater than five times the length of the picture height, a 525 line broadcast picture is generally sufficient, but close viewing may require that the pictures have 750 or 1000 scanning lines to provide greater over-all picture resolution.

Projector performance characteristics, exclusive of optics, are comparable to monitors both in terms of bandwidth (8 to 10 Mc) and linearity. A number of projectors are capable of accommodating several different line standards.

TELEVISION TAPE RECORDERS

There are several different categories of television type recorders. They can be classed as broadcast or non-broadcast, portable or non-portable, transverse scan or helical scan, and multiple-head or single-head. However, the important factor in the designation or selection of a television tape recorder is the specific application for which it is intended, its compatibility with the system in which it is used, and its versatility in meeting a range of requirements.

It is important to understand that a tape recorded on a non-broadcast machine cannot be played back directly on a broadcast machine because the magnetic signal paths traced on the tape by the recording head of one recorder may be curved or slanted (helical) while the signal paths on another recorder may be straight.

Portable recorders are relatively new and machines made by different manufacturers operate at different speeds. As a result there is presently not much possibility of exchanging tapes between machines made by different manufacturers. Most broadcast recorders operate with fifteen inch-per-second tape speeds and some have an optional seven and one-half inch-per-second capability.

Two operational factors concerning the use being made of tape recorders are worthy of discussion. These are: (1) the capability of new broadcast recorders to operate at one-half the normal fifteen inches-per-second speed and (2) the tendency of users to allow tape recorder capability to govern over-all system quality.

The possibility of recording on magnetic tape which travels at 7-1/2 inches-per-second is attractive because it is expected that twice as much information can be put on one tape reel and therefore that tape cost can be reduced. This is not the whole truth. Tapes recorded at 7-1/2 inches-per-second wear approximately twice as fast as those recorded at 15 inches-per-second and total tape wear is thus nearly the same. Reduction in possible picture quality, and tape recorder head wear are additional limitations of machines that operate at 7-1/2 i.p.s. Savings in tape cost and storage space can occur where large libraries of reference tapes are kept, but little savings can be expected where tapes are played often.

The tendency to permit tape recorders to govern the over-all system quality is apparently due to the feeling that tape exchange is currently the most practical method of information exchange. This method may seem to be inexpensive, but quality and immediacy are sacrificed. Trouble has also been encountered in accomplishing high quality playback because of the difficulty of keeping recorders properly setup and maintained.

There is no doubt that tape recorders will be part of any extensive educational television system, but acceptance of them requires acceptance of certain compromises because of the present state of television recorder development. Tape recorders, which must be of a "standard" variety for tape exchange purposes, are such an important and expensive part of any system that their use creates a tendency to make the rest of the system conform to the recorder capabilities.

For a number of operational reasons it is often desirable to create a recording center where most of the recording is done.* Studio and program facilities may be nearby or interconnected to the recording center by microwave or cable. If such a recording and tape storage center exists it is often possible to justify a scan converter, as the presence of even a single scan converter at a central recording center then releases the whole system from strict adherence to the system standard and restores full flexibility to the system. Schools which have special needs can satisfy their individual needs at their locations and can send "noncompatible" programs through the interconnection system to the conversion and recording center only when recording of certain programs is needed.

In educational television there has been a tendency to follow the lead of commercial broadcast television because of the ready availability of equipment developed through the demand for home television. Fundamentally, there is no reason why equipment cannot be built to operate on different standards to fulfill different needs.

There is also no reason why equipment with different standards cannot be built to meet other special needs. To the extent that broadcast channels are used to transmit educational television to the general public, the standards must be those used in broadcast television. However, where the points of reception are integrated into an educational television system that is not limited to customary home reception, there is no technical reason why higher standards suited to the particular need of each point should not be used.

The same transmission systems can accommodate any number of different standards as long as the individual standards do not require any greater bandwidth or more stringent system tolerance than is inherent in the transmission system. If this capability exists, then the only problem is to insure that those for whom the transmission is intended have receiving equipment that employs the same line and frame standards as the equipment used at the point of origin, or that proper conversion equipment is provided. The transmission system itself is not affected by the particular standards at any given time.

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*Experienced operating and maintenance personnel are hard to find; greater back-up capability is provided; the total recorder cost may be less because fewer recorders may be needed.

TABLE II
SUMMARY OF STATE OF THE ART OF TELEVISION EQUIPMENT
(June, 1964)

ITEM	PRESENT USE	FUTURE POSSIBILITIES
Camera	Many line standards are available. Vidicon and image orthicon camera roughly comparable in regard to inherent resolution, but have other operational differences.	Nominal 1200 lines horizontal resolution. New tubes have 1500-2000 line capability.
Monitors.......	As good as camera for any line system. Bandwidth is normally 8 to 10 Mc.	Monitors can have the same resolution as the camera.
Receivers......	Limited broadcast standards by 525 scan lines in the United States, resolution is at best 350 lines and is normally lower, and results are generally below state-of-the-art capability.	Very little change probable in black and white broadcast rereivers, although improvements are possible. New color techniques in experimental stages.
Projection System	Limited by optics. Geometric distortion may be severe and screen light levels may be inadequate.	Can be made to the same standards as the camera and some geometric distortion can be corrected. Screen light levels may be increased.
Tape Recorders . .	High quality units are normally made to color broadcast standards. Higher than U. S. broadcast quality units exist and are being developed here. Low resolution (200-300) line portable recorders are widely available, are often incompatible.	Non-broadcast recorders are being extended to color and to the limits of the broadcast system. New accessories will be available.

The fact that broadcast standards are not adequate for all applications in educational television is well recognized. Users who have been compelled to use different standards to obtain higher resolutions in certain applications have used a closed-circuit system, which is not limited by broadcast standards. As further experience is gained with educational television, there will be more and more applications that require special techniques; therefore, it is important that consideration be given not only to the provision of higher resolution standards to achieve higher performance, but also to the establishment of lower resolution standards where the requirements are such that satisfactory performance can be achieved with less bandwidth. There is no technical reason why several standards cannot be made available in the same receiver without a disproportionate increase in complexity and cost. Some receivers which have these standards already exist. Their increased availability will depend upon the demand that develops.

It is important to realize that the achievement of compatibility through adoption of a single television picture standard requires the loss of considerable flexibility in the possible use of educational television and in the efficient use of the radio spectrum. It also reduces the possibilities for optimizing the exchange of information via television with other nations of the world which use other standards, and with closed-circuit systems which have requirements for standards other than broadcast standards.

II

An Interconnection Network for Educational Institutions

THE REQUIREMENTS OF EDUCATION AND HOW TO DETERMINE THEM

The potential improvement of television quality is important in any specific situation, for it is on this basis that the successful use of television for instruction and other educational purposes must rest. To know that the broadcast standard with which we are all familiar from home viewing is but one of many possible standards is to consider television for a variety of uses which to date might have seemed impossible.

Standards for television are particularly critical when one plans for the interchange of television lessons and educational programs. Where systems are interconnected, either on a live basis or by means of television tape, they must be compatible, or the exchange of such data will not be possible.

The engineering of an interconnection network begins after the educational requirements which the network must serve have been carefully defined. Although engineers should assist in defining these requirements, it is primarily the task of the educators to outline the basic needs. Some typical questions which must be answered are:

(1) Who is to be served and at what locations?

(2) What type of information is to be exchanged between any two locations?

(3) What quality must be associated with each type of information exchange?

(4) What priorities will be established between (a) who is to be served and (b) what types of information are to be exchanged between any two separate points?

Answers to the first question concerning the persons and organizations served, might include schools, universities, hospitals, or the general public. A complete answer would necessarily include identification and location of specific schools, universities, hospitals, and broadcast stations, plus the designation of which would originate information, which would only receive, and which would have both capabilities.

In the case of a state-provided educational television network, for instance, it may be possible to combine certain other types of state communications in the network. These may be included directly in the microwave channels by multiplexing, or through separate RF channel equipment located at the relay stations of the educational network. If inclusion of other communication facilities is desired, all state services capable of benefiting should be considered and identified.

The answers to question two concerning types of information should be specified according to kind and direction. The kinds of information might be identified as black and white television, color television, high fidelity sound, telephone, or teletype. Attention must be devoted in this instance to special requirements which apply only to specific points. For instance, it might be possible to satisfy all network needs with black and white television, except that it might be necessary to provide color television between two medical colleges.

Other special requirements might include the need for high resolution television interconnection between two libraries or the need for high fidelity sound interconnection between two music centers.

Specification of information type should also include the amount of information to be exchanged between locations and the direction in which the exchange is to be made. It may be that multiple television channels will be required in one direction between two points while only one channel is necessary in the reverse direction.

Question three may be the most difficult to answer, and the one on which some technical assistance might prove most helpful. "Quality" implies the fidelity of a sound channel, the degree of resolution obtainable in a picture channel, or the keying rate obtainable in a teletype channel. It is particularly important to remember that in closed-circuit operations, one is not limited to the broadcast television standards set by the Federal Communications Commission.

Less than broadcast picture quality might be acceptable where the television picture is used simply as an adjunct to sound transmission, as might be the case in a speech, music, or most lectures. However, if a television system is to be used for more than one type of program material, it should be designed for the highest quality transmission likely to be required.

If there are television channels that would be used almost wholly for transmitting still scenes or pictures involving little or no motion, these should be so identified. Examples of this include transmission of printed pages of text, figures, or perhaps microscope slides from a pathology laboratory to surgeons. Such material offers an opportunity to conserve bandwidth by reduction of frame rate, without the loss of resolution.

With respect to sound, it would be desirable to maintain high fidelity standards for the transmission of music or for teaching foreign languages. Lower standards may be acceptable where the sole purpose is simple voice communication. Teletype standards can be readily determined from current and predicted message rates.

Probably the most useful answer that the educator can provide to question three is an accurate description of the use to which each information channel is to be put. Decisions regarding quality can then be made from this description.

Establishing a priority for the various services desired in a statewide network, in answer to question four, facilitates a number of decisions regarding cost and switching problems. In a network limited by budget, this priority determines which services will be provided at the beginning and which will be deferred or omitted. This is an especially difficult requirement to satisfy when attempting to interconnect new and existing facilities, but to neglect it may result in unnecessary limitations on network flexibility and utilization. It is only after the needs have been accurately assessed that economic compromises should be considered.

TRANSLATION OF REQUIREMENTS INTO TECHNICAL TERMS

Just as defining the requirements is primarily the responsibility of educators, translation of these requirements into technical terms is the responsibility of engineers. The answers to the questions posed above constitute, in effect, a definition of requirements. They provide the basis for determining the design objectives of the interconnection system. With a definite idea of requirements and objectives, the engineer can begin to identify locations for transmitters, receivers, repeaters and switching points.

The specification of who is to be served will direct the establishment of network routing and identification of switching and end-points. Determining the kind of information and the points among which it is to be interchanged will assist in defining the number and direction of microwave communication channels.

The indication of information quality will permit determination of the necessary channel bandwidth and will be the basis for definition of the signal-to-noise ratio that must be maintained in various parts of the system. Reliability will be an important addition to the statement of necessary quality. All three of these factors, bandwidth, signal-to-noise ratio, and reliability, provide a foundation for actual network development and calculations.

Priorities will provide the basis for cost compromises and may enter into the determination of switching points. They are often an important factor in determining the time-table of system development.

TYPES OF TELEVISION DISTRIBUTION AND INTERCONNECTION SYSTEMS

There are two basic types of television transmission systems: (1) distribution systems and (2) interconnection systems. A distribution system is one that provides a direct link to the user and an interconnection system interconnects distribution systems.

The most typical type of distribution system is a television broadcast station. The most common type of interconnection is a microwave system, or an inter-point cable system. Translators (See Figure 3) are distribution systems of a particular type which also provide a relay function; they are distribution systems that use information picked up from another distribution system. Still another pattern sometimes used, shown in Figure 4, is the "off-the-air" pickup and microwave relay. In this case, a distribution system also functions as the first link of a multihop interconnection system.

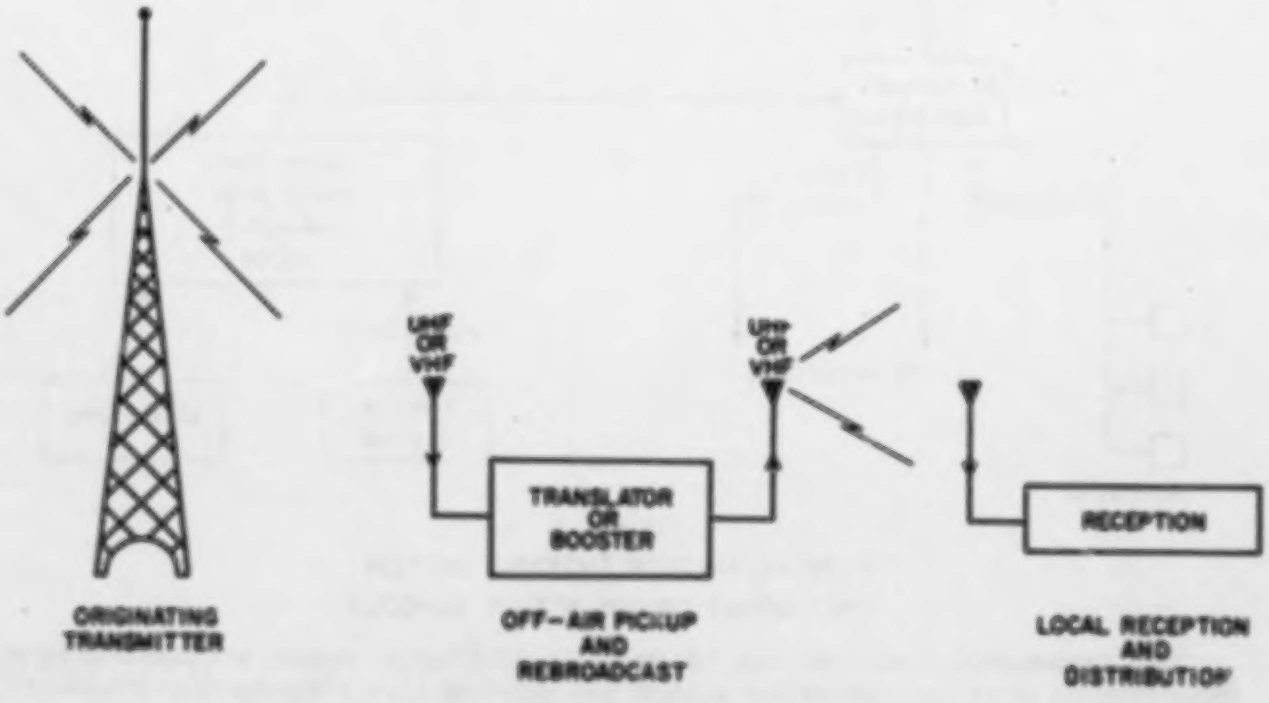

FIGURE 3
TRANSLATOR

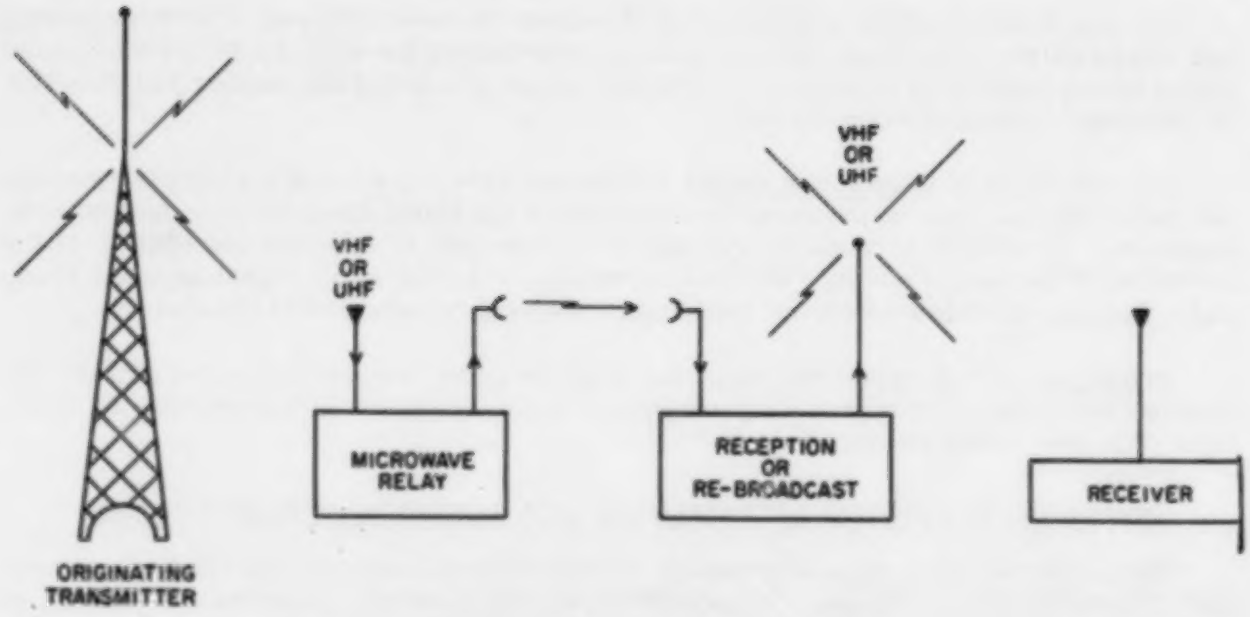
ORIGINATING TRANSMITTER
VHF OR UHF
MICROWAVE RELAY
VHF OR UHF
RECEPTION OR RE-BROADCAST
RECEIVER

FIGURE 4
OFF-AIR MICROWAVE RELAY

Coaxial cable can be used in distribution systems and for interconnection. Figures 5 and 6 show a typical master antenna system and a video distribution system which would normally be employed as the internal distribution system of a building.

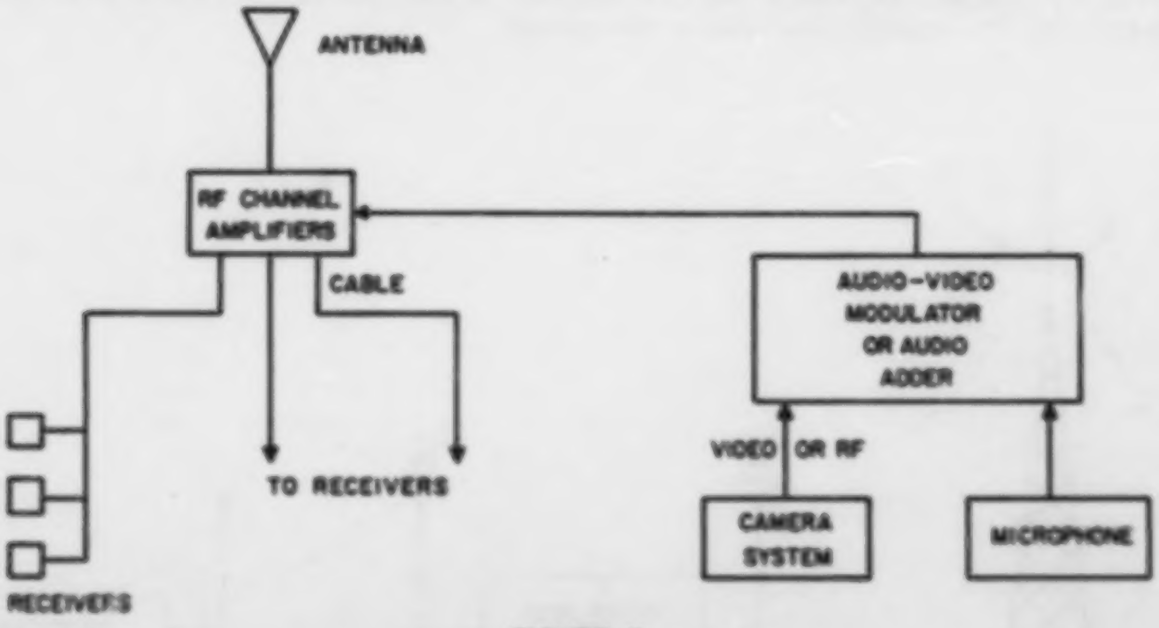
ANTENNA
RF CHANNEL AMPLIFIERS
CABLE
TO RECEIVERS
RECEIVERS
AUDIO-VIDEO MODULATOR OR AUDIO ADDER
VIDEO OR RF
CAMERA SYSTEM
MICROPHONE

FIGURE 5
TYPICAL MASTER ANTENNA SYSTEM
(INCLUDING ORIGIN WITHIN SCHOOL)

The fundamental considerations relating to a distribution system are different from those relating to an interconnection system and different design objectives are therefore used for each type of system. These are discussed with respect to broadcast and microwave relays in Appendix B. Particular concern must be given before permitting compromise of these objectives at any time that one station is used to serve both functions.

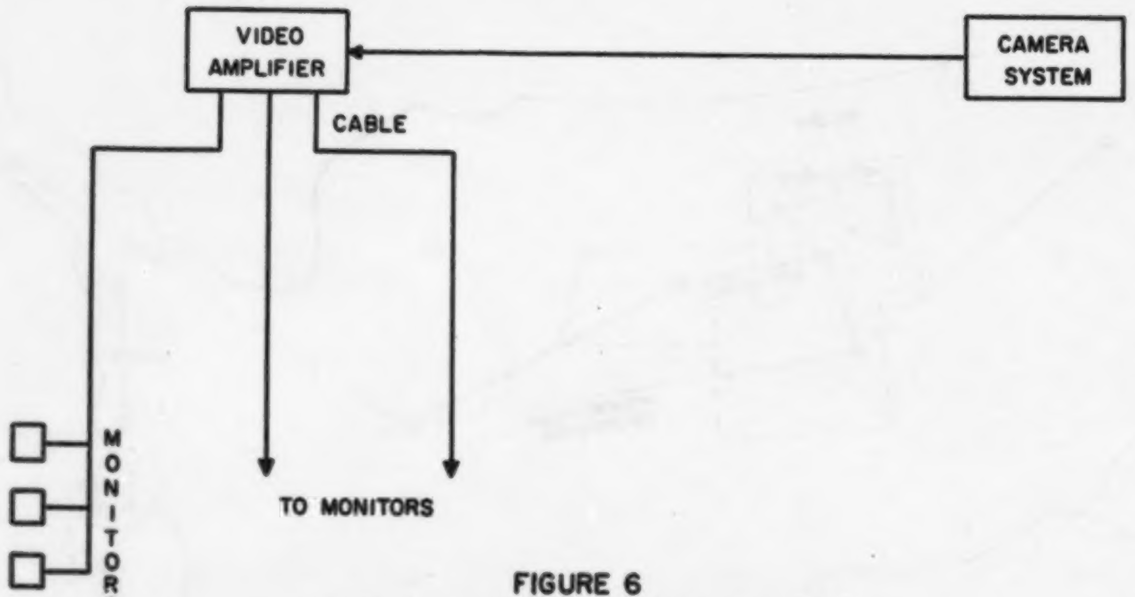

FIGURE 6
TYPICAL VIDEO DISTRIBUTION SYSTEM
(CAN INCLUDE SOUND AND/OR BE DISTRIBUTED BY RF)

The principal concern with a distribution system is to provide the necessary coverage to reach the users. Emphasis is placed upon achieving maximum coverage of a geographical area.

In interconnection systems, major concern must be given to maintaining a negligible degradation of relayed signals. The over-all system should be designed to provide coverage with maximum economy, including economy of spectrum use, and to assure minimum signal degradation.

It should be obvious that when a distribution sytem is used for relaying the received signal from a second distribution station, there is likely to be significant degradation of quality. This is a function not only of the difference between an interconnection system and a distribution system, but of the likelihood of a co-channel interference which may occur when receiving the "off-air" signal from the broadcasting station. For this reason, the use of off-the-air pickup should be avoided in an interconnection system, since its use involves a distribution station that, by design objective, may have qualities which, though entirely satisfactory for a broadcast (one hop) system, cannot be tolerated in a multihop interconnection without seriously degrading the transmitted signal.

Figure 7 shows several networks identified according to the area covered. The choice of carrier frequency, power, bandwidth, and location of stations for each one is affected by the performance requirements and the length of the system to be served. The longer the system, the more stringent are the technical requirements imposed at each relay station, because more stations are involved and each contributes something toward signal degradation.

There are two basic types of interconnection stations: (1) long haul stations, or those links that are a part of a backbone system, and (2) spur stations, or those links off the backbone system (See Figure 8).

Different technical requirements can be set for the two types of stations. The backbone system carries the information intended for long haul transmission, which might include transmission through several states. Spurs should carry those transmissions that involve

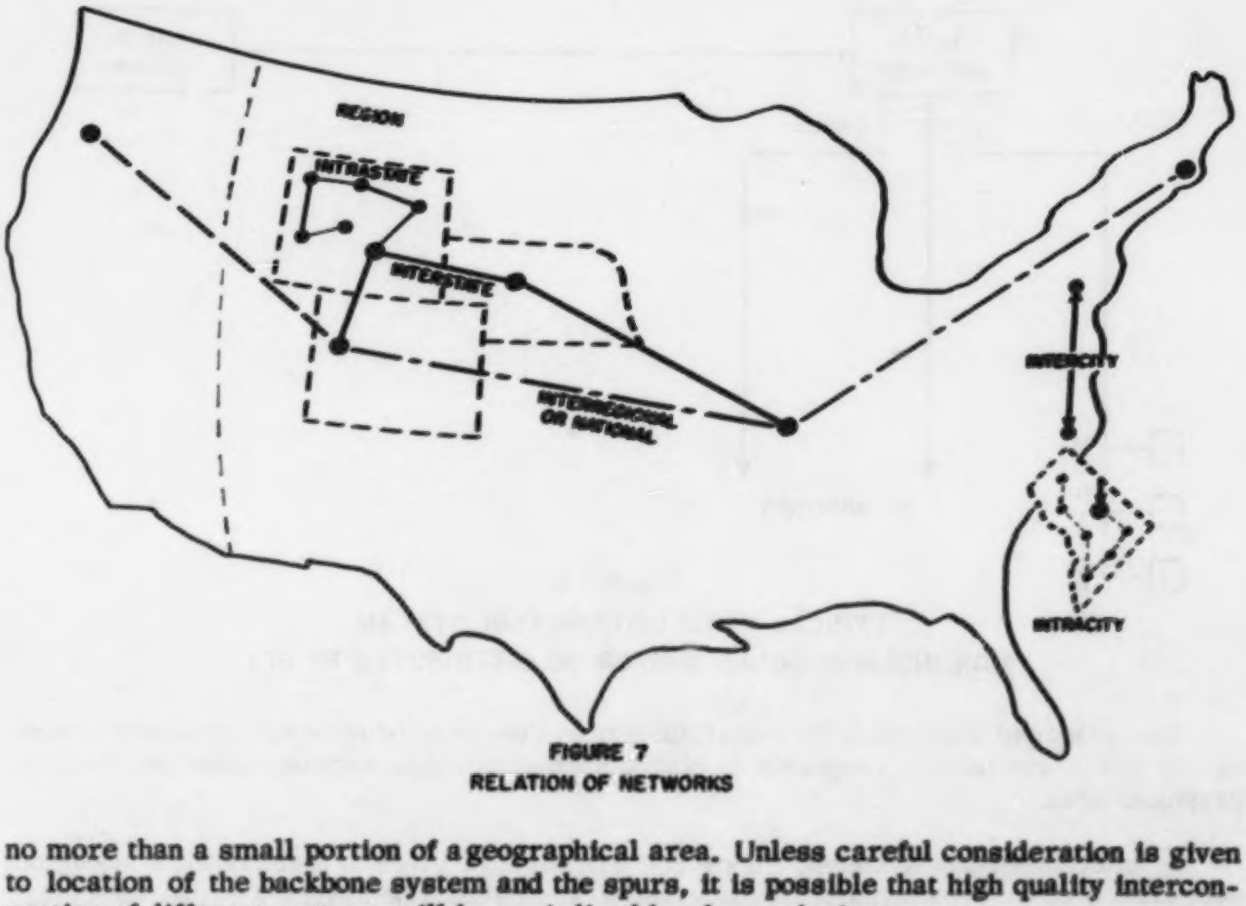
REGION
INTRASTATE
INTERSTATE
INTERREGIONAL OR NATIONAL
INTERCITY
INTRACITY

FIGURE 7
RELATION OF NETWORKS

no more than a small portion of a geographical area. Unless careful consideration is given to location of the backbone system and the spurs, it is possible that high quality interconnection of different systems will be prejudiced by chance design.

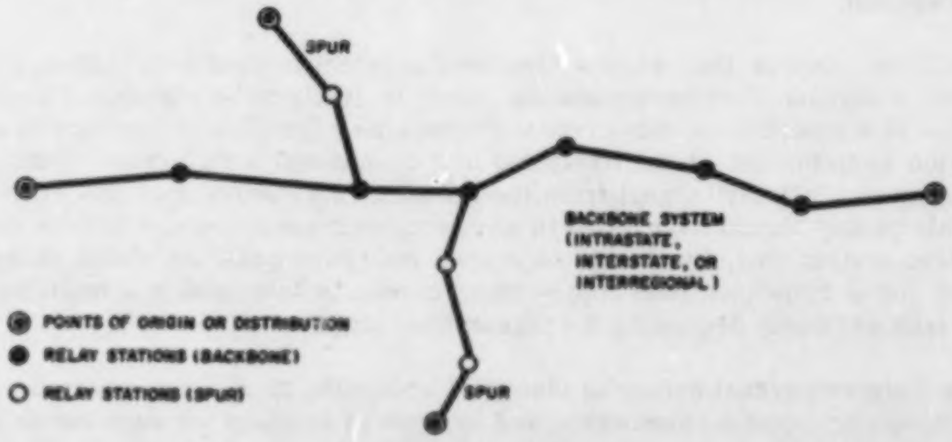
SPUR
BACKBONE SYSTEM (INTRASTATE, INTERSTATE, OR INTERREGIONAL)
POINTS OF ORIGIN OR DISTRIBUTION
RELAY STATIONS (BACKBONE)
RELAY STATIONS (SPUR)
SPUR

FIGURE 8
ILLUSTRATION OF BACKBONE AND SPUR STATIONS

Common Carrier or Private Microwave

After requirements have been defined and essential network characteristics have been determined, concern can be shifted to how interconnection may be provided.

There are currently two methods of providing interconnection. One is to apply to the Federal Communications Commission for microwave channel licenses for a privately-owned microwave network. The other is to lease similar facilities from a common carrier. Each method provides certain advantages and disadvantages that must be considered in relation to the defined system requirements.

Recently, common carrier systems have become more competitive with privately-owned systems as a result of a tariff that establishes special services and rates that are intended to provide economical interconnection services for educational television. Such rates have been established by law, but the laws do not define the kind of equipment or grade or quality of service to be furnished educational institutions under the lower rates. The tariff is not usually negotiable with the common carrier, but there is a wide range of equipment and service that common carriers may legally offer; however, the burden of specifying and negotiating for the quality of service to be provided by the common carrier is imposed upon the educational agency or group contracting for such services.

Rates lower than those charged under the commercial interconnection tariffs are available in the educational television tariff because the services provided for customers of the educational television tariff are different from the interconnection services provided to customers of the commercial tariff.

Although the equipment used by the common carriers is technically capable of providing up to 8 Mc video transmission, the service only provides for 4 to 4.5 Mc, although in special instances they have specified 8 Mc video transmission. The technical facilities provided by the common carrier would probably allow the multiplexing of additional information onto the video channel. However, the tariff service description may prohibit this type of operation. It is possible that this prohibition may not apply to certain intra-state situations. The provision of additional information, such as fault alarm, order wire, audio channel, or digital transfer, which would be desirable multiplex channels, is currently available only under other tariffs at commercial rates.

The question of whether the common carriers can provide certain services with regard to intercommunication and switching remains unanswered because the common carriers have not had occasion to consider this matter. Particular undecided situations include: (1) connecting with customer facilities at the intermediate frequency of a common carrier heterodyne repeater; (2) clarification of the "in attendance" stipulation at signal source points, i.e., whether it is possible to make some arrangement with the phone company to insure maintenance at points having both company-owned, and privately-owned facilities; (3) the possibility of connection at a repeater station if a man is in attendance. This applies particularly to the possibility of interconnecting with other statewide systems; (4) the general rules on switching, and where switching can be performed.

Common carriers will provide both open and closed circuit interconnection services under the educational television tariff for any percentage of the time desired. However, since the same points in a system do not usually have both open circuit and closed circuit requirements, it is necessary to have switching; switching is not provided for in the educational television tariff. A channel in the educational television service is one way from one premise to another, and the direction of transmission cannot be reversed.

If it is desired to implement a private microwave network, the equipment available for purchase in general meets or exceeds all reasonable system design characteristics. It can carry a high quality color television signal meeting performance specifications to both intrastate and interstate locations. In addition, the facilities provided by private suppliers could be used for better resolution 525 line television, higher line standards, e.g., 625, 675, 819, computer data, high quality audio channels, voice channels, or teletype services.

One of the most serious deterrents to the implementation of a private system, however, is the present FCC allocation policy concerning frequencies available for use in a private system. This policy limits RF bandwidths for closed-circuit television interconnection purposes* to 10 Mc. The 10 Mc channels are entirely unsuitable for the relaying of television, and do not even permit the transmittal of a minimum quality monochrome signal.

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*The allocation structure of FCC Rules permits 25 Mc bandwidths under the Rules governing the use of microwave stations that serve broadcast stations.

The most obvious advantage of a private microwave system is flexibility. Equipment and sites can be chosen with future expansion in mind. Additions and changes can be readily effected. Normally, one would expect to exert very little control over the selection of common carrier equipment and sites, so long as services provided by the common carrier meet with the terms of the agreement. Additions and changes would, in each individual case, require negotiations with the common carrier over his willingness to make such changes and the resulting changes in tariff structure. Policy and legal aspects may enter into such negotiations.

Alternatively, the most obvious advantage of utilizing common carrier services is the avoidance of a large initial capital outlay. Any financial outlay required for facilities is borne by the common carrier, but he in turn may require a ten-year decreasing liability agreement to protect his outlay. Under such an agreement, the agency would not be able to drop the services of the common carrier within a ten-year period without payment of the remaining liability.

Educational organizations concerned about interconnection of educational facilities would do well to investigate both the possiblities of common carrier and private microwave networks, including the tariff provisions of the former versus capital outlay and depreciation of the latter. Technical requirements should be firmly defined before such an investigation is made to make certain that what is compared is technically equivalent. There is likely to be a reluctance on the part of a common carrier to consider a departure from what may seem to be conventional, standard, or "adequate" – a further reason for carefully defining technical requirements before beginning negotiations. Only after such an investigation can a decision be made based on comparative costs, adequacy and flexibility.

III

Technical Flexibility and Various Educational Needs

Relating educational needs and the technical characteristics of a television system to meet those needs is fundamental to proper planning. Such planning should not be prejudiced by a fear that a change from the use of television standards different from broadcast standards will involve a significant increase in cost.

Throughout the world a number of different standards have been used, depending upon the particular compromise arrived at to standardize broadcast facilities in each country. A particularly important consideration in adopting U. S. Standards has been the use of a minimum channel width consistent with acceptable quality on a receiver that is commercially and economically practical. The importance of spectrum conservation and the need for a large number of channels for omni-directional broadcast have been vital considerations, but in the case of non-broadcast situations, these limitations do not apply.

DIFFERENCES BETWEEN INTERCONNECTION AND BROADCASTING

In relating the technical characteristics of radio and television to educational needs, it is important to recall that a difference exists between the problems involved in broadcasting a signal from the transmitter to the user's receiver, and "networking" a signal, or interconnecting widely spaced distribution points with the place where the television signal originates. Where broadcasting involves only one transmission step, from the transmitter to the receiver, networking may require as many as one hundred steps (or "hops") of transmission, reception, and retransmission.

The important difference is that in the broadcasting all allowable degradation effects can and do occur in a single transmission and reception process. Such degradation is accepted because as much coverage as possible is achieved at a reasonable cost within a minimum amount of frequency space.

In the case of interconnecting or networking, the degradation in the total relaying process must be negligible so that neither the reception quality nor coverage from a distribution point located anywhere along, or at the end of a network, is significantly affected by the distance from the place where the program originates.

Because of the emphasis upon transmission quality in networking the important system characteristics in interconnection systems are different from those characteristics in broadcasting. A particular result of this difference in emphasis is the justification for wider bandwidth in network transmission. It is important to recognize that the need for wider bandwidth in networking is directly related to the need to minimize degradation of the television signal when it is sent over long distances via a microwave network. The amount of bandwidth required in a given channel is directly related to the nature of the information and to the type of modulation used to relay that information effectively.

A further factor that has an effect upon the bandwidth requirement in networking is the need to isolate the different information signals that comprise a given transmission. For example, it is important to provide adequate frequency separation between the picture signal and the sound signal so that they do not interact with each other and that insignificant distortion occurs in the process of separating these signals.

An important fact that is sometimes overlooked in relating broadcasting techniques to networking is the compromise standard that exists in broadcasting – a standard that involves the use of a minimum channel width (6 Mc) – to include a complete television program consisting of both video and audio. To confine a television program to 6 Mc involves a very tight "fitting" of picture, sound, and synchronizing signals, and results in a situation which can be tolerated only on a singlestep basis. On a networking basis, this practice of maintaining the tight compromise required for a 6 Mc transmission could result in significant impairment of picture and sound quality. For networking purposes, therefore, it is customary to employ a wider frequency spread between the audio and video signals than in broadcast transmission. With this method it is possible to transmit a wider video channel without interfering with the sound than is feasible with broadcast standards.

In those interconnection systems where the sound is multiplexed with the video, the composite signal as a whole is retransmitted at each relay station, without the customary processing of video and sound at each relay point. This technique is referred to as heterodyne relaying and is discussed in detail in Appendix B.

THE IMPORTANCE OF BANDWIDTH IN INTERCONNECTION SYSTEMS

The most important consideration in engineering microwave television networks is the use of sufficient bandwidth to permit high quality relaying on an economically sound basis using available "state-of-the-art" equipment. To accomplish this, it is desirable to obtain the advantages inherent in the use of frequency modulation (FM) techniques. Amplitude modulation (AM) is not normally used for interconnection purposes.*

With FM, multi-hop relaying is possible and signal quality can be improved significantly by the use of increased bandwidth as well as by increased power. FM has the desirable characteristics of permitting high quality transmission with efficient use of transmitter power capability.

The degradation that an audio or video signal suffers in transmission is actually due to two things. One is the accumulation of electrical "noise," and the other is the "distortion" of the signal that occurs each time the signal passes through a receiver or transmitter. Neither noise** nor distortion can be completely eliminated from electrical signals, but both can be minimized by the use of the correct modulation techniques. Increased RF bandwidth is usually necessary to accomplish this.

In the case of degradation due to noise, it must be understood that noise accumulates at each element of a system. If there are ten equivalent relays in a microwave interconnection system, then the total noise power level that is accumulated is ten times that which would accumulate in one. To maintain a given quality each input signal must be 10 times stronger than required for one-hop transmission. If a signal is to be transmitted over 100 hops, the noise power accumulation is 100 times that of a single hop.

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*In broadcast television, however, vestigial sideband (VSB) modulation is used for transmission of video to minimize bandwidth requirements. With this technique, increasing the bandwidth of the transmitted signal only makes the picture quality worse because of interference from electrical "noise." The only factor that will improve the received picture quality from such a VSB transmission is increased power. On microwave frequencies useful for networking, there are practical power limitations. Within these limitations, amplitude modulation techniques cannot maintain sufficient signal quality over a multiple hop system.

**The ratio of signal power to noise power is a convenient and often used method of expressing one of the important characteristics of a received signal. A high signal-to-noise ratio is good, because it indicates a low level of interfering noise.

In such cases an improvement in signal-to-noise ratio of 10 times (or 10 db) for 10 hops, or 100 times (or 20 db) for 100 hops, is the requirement imposed upon each hop in the multiple-hop network over what would be satisfactory for a single hop (e.g., broadcast) system, assuming that all hops have equivalent characteristics. This requirement alone poses a significantly different problem for a microwave interconnecting system as compared with standard broadcasting.

With frequency modulation, an improvement in the ratio of signal-to-noise can be realized over that which can be achieved with vestigial sideband amplitude modulation. The ratio of this improvement is referred to as the "wide-band gain" or "noise improvement factor." This improvement requires additional bandwidth, but what is important is that, with the use of FM, there is the possibility for minimizing degradation per hop and that the power required to overcome noise can be considerably less than would be required with amplitude modulation techniques.

With frequency modulation, an improvement in terms of minimizing distortion is realized even though the deviation ratio* (bandwidth increase to overcome noise) used is relatively small. However, to achieve maximum benefit from frequency modulation involves a need for sufficient use of RF bandwidth and power in overcoming noise effects to permit achieving system requirements with reasonable economy when employing presently available equipment.

Figure 9 shows the relationship between deviation ratio (or modulation index) and the FM improvement factor. RF bandwidth, of course, increases with the deviation ratio. This shows what can be obtained from the proper use of frequency modulation. It will be seen that there is a significant improvement realized as the deviation ratio increases from less than 1 to about 2.5. At a deviation ratio of 2.5 the improvement is 10 db. This means that the signal-to-noise ratio of the received signal is 10 times better than it would be if the type of modulation employed in television broadcasting were used.

Figure 10 shows the relationship between FM improvement factor and a bandwidth multiplying factor. According to this figure, the improvement of 10 db obtained with a deviation ratio of 2.5, required an RF bandwidth of 7 times the information bandwidth. This would result in a bandwidth of 30 Mc for a 4.2 Mc video baseband signal, adequate for 525 line television.

The requirement of 30 Mc is more than is allowed by existing FCC Rules, but technically it is quite feasible. With it, an improvement of 10 db, or the equivalent of 10 times in power, can be realized.

The preceding example referred to the transmission of a video information signal only. In practice, there is need for transmitting both video and audio signals. However, the normal sound signal used for television is an FM signal and therefore already has the

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*"The deviation ratio," or "modulation index" as it is frequently called, is the ratio of the FM carrier frequency excursion to the highest baseband, or modulating frequency. The relationship between RF bandwidth and deviation is given by

RF Bandwidth = 2F (1 + M)
where
F = highest modulating frequency M = deviation ratio

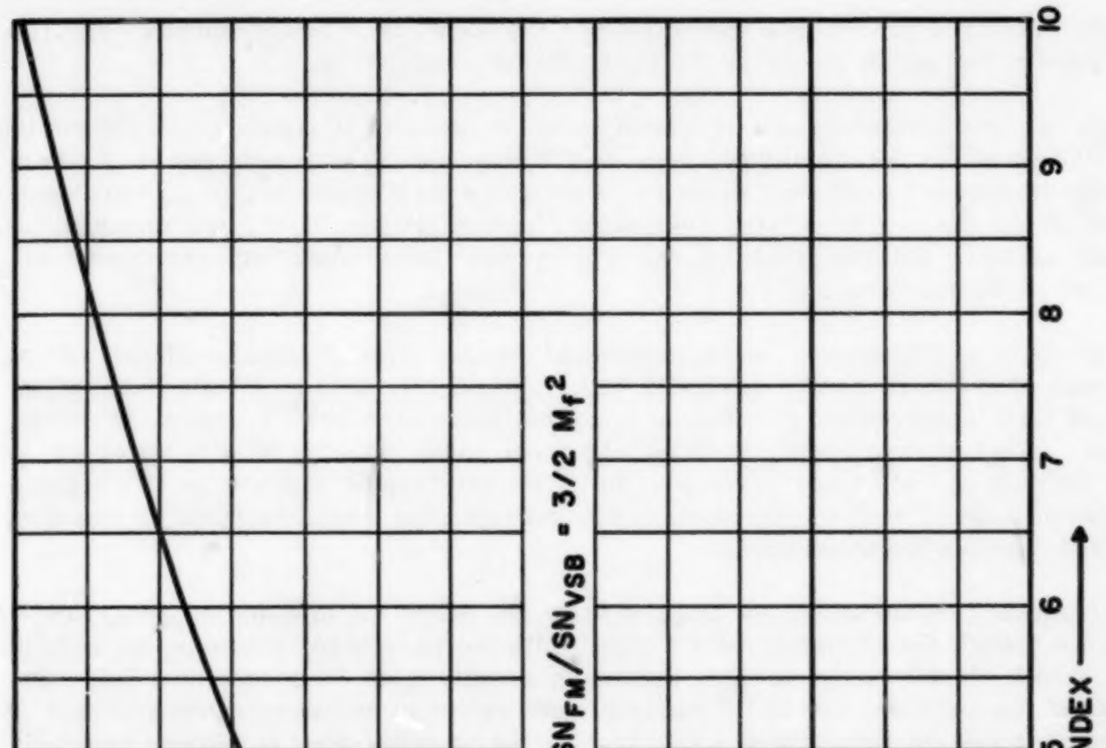

FIGURE 9

OUTPUT SIGNAL TO NOISE IMPROVEMENT OF FM OVER VSB VS. MODULATION INDEX

modulation characteristics required to suppress noise. Thus in the relaying process, the need for additional improvement of the audio is small. The principal emphasis can be given to the frequency modulation of the video signal.

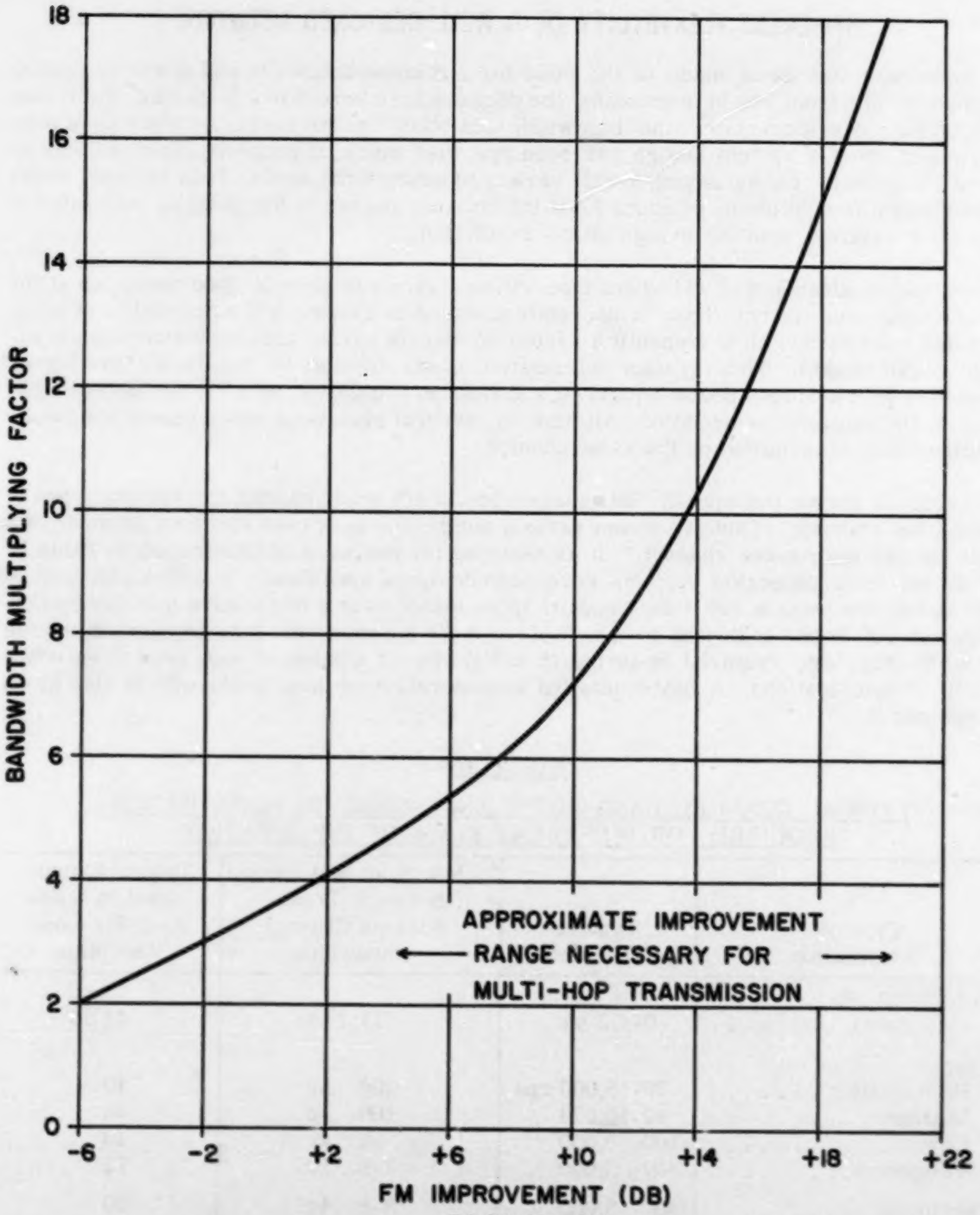

FIGURE 10

INCREASE IN BANDWIDTH REQUIRED TO REALIZE, WITH FM, IMPROVEMENT OVER BEST POSSIBLE AM NOISE PERFORMANCE AT THE SAME POWER

INHERENT FLEXIBILITY OF A WELL-DESIGNED NETWORK

Reference has been made to the need for sufficient bandwidth and power to realize optimum benefit from FM in overcoming the degradation inherent in a long-haul, multi-hop interconnection system. Once the bandwidth and other system characteristics have been determined, then a system design has been specified which, if properly exploited, has an inherent capability for satisfying a wide variety of educational needs. This includes needs for handling different forms of educational information and needs for handling television of different standards resulting in high or low resolution.

By taking advantage of wide-band modulation systems to provide good reception at the end of a long-haul system, there is inherently provided in a network the possibility of using the same wide bandwidth to transmit a variety of signals having varying information bandwidth requirements. Thus greater information bandwidth can be used to achieve higher resolution, provided less deviation is used, and reduced reliability, or a shorter total transmission distance can be accepted. Alternately, several signals of lower resolution can be simultaneously transmitted on the same channel.

Table III shows the specific information bandwidth requirements for various types of information transfer. Table IV shows various combinations of uses that may be made of a single 30 Mc microwave channel.* It is assumed for purposes of illustration in Table IV that 30 Mc interconnection systems have been designed specifically to prove high quality color television with a 525 line standard (plus audio) over a microwave interconnection system of 100 hops. Indicated in the Table are the services that may be carried and the trade-offs that are required in terms of reliability or number of hops used to satisfy a variety of combinations. A more detailed consideration of these trade-offs is also given in Appendix B.

TABLE III

TYPICAL CHANNEL BANDWIDTHS AND SIGNAL TO NOISE RATIOS REQUIRED FOR DIFFERENT KINDS OF INFORMATION

Type of Information	Typical Baseband	Minimum Multi-hop Network Transmission Channel Bandwidth	Typical Output Signal to Noise Ratio for Good Reception
Television			
(525 lines)..........	0-4.2 Mc	13.2 Mc	42 db
Voice			
High Quality	20-15,000 cps	200 kc	40
Medium	40-10,000	100 kc	40
Low..............	100- 5,000	50 kc	40
Telephone.........	300- 3,000	3-6 kc	12
Facsimile	300- 3,000	3-6 kc	20
Control and Fault Alarm.	0- 1,000	1 kc	12
Teletype or Data......	0- 120	120 cps	12

Assuming the availability of a 30 Mc channel, any of these combinations of uses involves no change in network characteristics – no adjustments at relay stations – only the

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*The derivation of these requirements is discussed in Appendix B.

TABLE IV

FLEXIBILITY IN THE USE OF A 30 MC BANDWIDTH MICROWAVE INTERCONNECTION SYSTEM

No. of Hops	Transmission Reliability	No. of Video Channels and Bandwidth	No. of 15 KC Voice Channels	No. of 3 KC Voice Channels	No. of TTY Channels
100	99.9	1 (4.5 mc)			
50	99.9	1 (4.5 mc)	3-6		
50	99.9	1 (4.5 mc)	1-3	10-50	
50	99.9	1 (4.5 mc)	1-3		150-200
10	99.99	1 (4.5 mc)	1		
10	99.95	1 (4.5 mc)	2		
10	99.9	1 (4.5 mc)	6-10		
10	99.9	1 (4.5 mc)		30-100	150
10	99.9	1 (9 mc)	1		
100	99.9	2 (2.2 mc)			
10	99.99	2 (2.2 mc)			
10	99.9	2 (2.2 mc)	3-6		
10	99.9	2 (2.2 mc)	3	10-50	

proper use of terminal equipment at each end point to match the input signal and the output signal characteristics on each separate information channel.

The possibilities for effective use of microwave networks are enormous. Equipment availability is no problem. The most serious requirement is for a determination of educational needs in given circumstances in the light of what can technically be provided.

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IV

Frequency Bands Available for the Interconnection of Educational Television Systems

Radiocommunication facilities are categorized for regulatory and administrative purposes according to both the type (or "mode") of operation and the nature of the licensees that operate the facilities. Blocks or bands of frequencies are then assigned for use by each of the many services within a given category. There are two modes of operation: (1) the Fixed Service, where the transmitter remains in one place, and (2) The Mobile Service, where the transmitter may be moved or is attached to a vehicle. The four most general types of allocation made according to the type of licensee may be identified as government, common carrier, industrial and private.

The frequency bands assigned to the federal government for the national defense are not available to private persons or groups and allocation of specific frequencies within these bands is not within the province of the FCC. The bands assigned to the common carriers (telephone and telegraph companies), while regulated by the FCC, are restricted from use by persons or groups, other than common carriers. The frequencies assigned to the common carriers are used by them to provide communications services to many customers, one of which could be an educational television network or station.

The frequencies allocated for private purposes are subdivided into individual services within which an educational television agency might operate an individually owned and controlled network. It is important to realize that the bands of frequencies assigned to a given service in the private allocation area are not always assigned exclusively to that service. That is, certain frequency bands may be shared by several services.

Educational television broadcast stations may operate by obtaining a license and operating in accordance with the *Rules and Regulations of the Broadcast Services*. Interconnection of broadcast educational television may be accomplished by obtaining licenses and operating within the Rules of the Television Auxiliary Broadcast Services.* Interconnection of closed-circuit educational television may be accomplished by obtaining licenses and operating within the Rules of the Business Radio Service** which is one of several services within the Industrial Services category.

If educational television must operate on a shared basis with the Broadcast and Industrial Services, there should be an examination to determine whether there is sufficient spectrum space, and the effect that a set of defined requirements would have on the space, both for ETV and for the assigned Service.

Referring to the Table of Frequency Allocations,† it can be seen that the Government and Common Carrier Services are assigned 2040 Mcs and 3505 Mcs respectively, of the

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*The Rules and Regulations of the Federal Communications Commission that pertain to Television Auxiliary Broadcast operations are contained in Subpart F of Part 4 of the Rules.

**Rules that pertain to the Business Radio Service are in Subpart L of Part 11.

† Section 2.106, FCC Rules and Regulations.

12,500 Mcs of the radio-frequency spectrum between 1,500 Mcs and 14,000 Mcs. Furthermore, 3025 Mc are assigned to the "mixed" (Government, Non-Government) Services and are used for such purposes as Radio Astronomy, Radio Navigation, and Earth-Space Communications. This space is not generally available for microwave interconnection. The actual amount of spectrum space that can be established as available for educational television interconnection is 1910 Mcs.

Since rain attenuation fading becomes appreciable above 8,000 Mcs it is useful to determine the amount of spectrum available both above and below this frequency. Of the 1910 Mcs possible available for educational television interconnection, a total of 860 Mcs is available below 8,000 Mcs, and a total of 1050 Mc is available between 8,000 Mcs and 14,000 Mcs.

The specific bands identified from the microwave frequency spectrum as being available in some manner for educational television interconnection are listed in Table V.

TABLE V

FREQUENCY BANDS POSSIBLY AVAILABLE FOR ETV INTERCONNECTION*

Bands (Mc)	Regulatory Service	Operational Service	Class
1850- 1990	Industrial	Fixed	IC&OF**
1990- 2110	Auxiliary B/C	Fixed & Mobile	TV Pickup & STL***
2450- 2500	---	Fixed & Mobile	Industrial, Scientific & Medical
6575- 6875	Industrial	Fixed	IC&OF
6875- 7050	Auxiliary B/C	Fixed & Mobile	TV Pickup & STL
7050- 7125	Auxiliary B/C	Fixed & Mobile	TV Pickup & STL
12200-12700	Industrial	Fixed	IC&OF
12700-13200	Auxiliary B/C	Fixed & Mobile	TV Pickup & STL
13200-13250	Industrial & Auxiliary B/C	Fixed & Mobile	---

*Does not include 2500-2690 Mc.

**International Control and Operational Fixed; such fixed stations are not open to public correspondence and are operated by a private agency.

***An STL is a studio-to-transmitter link.

It would appear from this extensive list that there should be little problem in finding frequencies for an educational television microwave network. If these bands are examined, however, numerous restrictions and prohibitive rule-making proceedings will be discovered. First, there are several bands which are entirely unsuitable for interconnecting educational television facilities. For example the 2450 - 2500 Mc band is not suitable for high quality interconnection, because microwave relay stations operating in this band would have to operate secondarily to industrial, scientific and medical equipment, and would, therefore, have to accept possible interference from such equipment.

The remaining bands identified in Table V are available for network interconnection if operation can be accomplished within the existing regulatory provisions and if present rule-makings do not further exclude them for educational purposes. General restrictions which apply regardless of band are:

(1) Operation in the International Control and Operational Fixed or Land Classes of the Industrial Rules must be accomplished under development authorizations (Section 11, Subpart E, FCC Rules and Regulations.) These authorizations require a factual showing of intended operations and, in addition, such authorizations may be changed or withdrawn, without possibility of hearing, at the discretion of the Commission (Section 11.207, FCC Rules and Regulations.)

(2) The interim technical standards governing the use of microwave frequencies within the Industrial Radio Rules (Section 11.111) provide the following:

Frequency Band (Mc)	Maximum Transmitter Power (Watts)	Bandwidth (Mc) Maximum
1,850 - 1,990	18	8
6,575 - 6,875	7	10
12,200 - 12,700	5	10
13,200 - 13,250	--	--

Consideration will be given on a case-by-case basis to requests for additional adjacent channels based upon a complete and specific factual showing of unique unusual circumstances, apart from economic consideration, requiring such additional channels.

(3) Educational institutions can qualify for closed circuit nonbroadcast licenses only in the Business Radio Service of the Industrial Rules. (Section 11, Subpart L, FCC Rules and Regulations.) The microwave frequency bands available to this Service that are suitable for television interconnection are: 6,575 - 6,875 Mc, 12,200 - 12,700 Mc and 13,200 - 13,250 Mc.

(4) Interconnection of broadcast educational material by intercity relay under the Auxiliary Broadcast Rules requires the sharing of available bands with television remote pickups, which are a mobile operation. Furthermore, STL authorizations are usually made on an exclusive basis in these bands, and available frequencies may thus become scarce in metropolitan areas.

SPECIFIC FREQUENCY BANDS

With these general restrictions in mind an examination of specific frequency bands is discussed below.

1,850 - 1,990 Mc

This band is not presently available for educational television interconnection in either the Auxiliary Broadcast or Business Radio Service, but there are several rule-makings seeking to make it available. In Docket No. 14896 the Commission has responded to a petition for rule amendment requesting that this band be made available for "Interconnecting Non-Commercial Educational Television Broadcast and Closed Circuit Relay Use." Specifically, the FCC:

1. Calls attention to another proposed amendment of its Rules (Docket No. 14894) to allow incidental sharing of Broadcast and Industrial licensed facilities for transmitting educational material.
2. Denies the petition to reallocate this band "to permit its use on a primary basis for interconnecting broadcast facilities."
3. Proposes amendment of the "Business Service rules to include the frequency band 1,850 - 1,990 Mc for use by educational institutions for closed circuit television

purposes." However, such use must meet the restrictions of the Memorandum Opinion and Order of Docket No. 11866. (See page 31 below)

1,990 - 2,110 Mc

This band is presently available for microwave interconnection of educational television broadcast material. However, it is available for television intercity relay only on the condition that no harmful interference is caused to TV pickup and STL operations. The assigned channels are 17 Mc wide.

6,575 - 6,875 Mc

This band was first identified as being "appropriate for intercity closed-circuit educational television" on a case-by-case basis in Docket No. 11866, Memorandum Opinion and Order. The policy expressed at that time was incorporated by the FCC into its Industrial Rules in the Business Radio Service. Under the rules of the Business Radio Service educational users have an exclusive intercity relay allocation, but they do not have exclusive use of the band since it may also be used by other regulatory services within the Industrial Rules. Closed-circuit educational users must operate with developmental authorizations, and must "furnish complete and specific factual data showing wherein, apart from economic considerations, it is not feasible to utilize frequencies above 10,550 Mc for such operations." (Section 11.554(b) (19), FCC Rules and Regulations.) The interim technical standards provide for a 10 Mc RF bandwidth, and also for additional adjacent channels, again on a case-by-case basis.

6,875 - 7,050 Mc

This band is assigned to the Auxiliary Broadcast Services and is available for intercity relay of broadcast material on the condition of non-interference to TV pick-up and STL operations. The regulatory actions affecting this band are Docket Nos. 14712 and 14729, Report and Order wherein it is suggested that this band is available to educational television for interconnection of broadcast material. No regulatory power limit for transmitters is specified for these operations, but stations will not be licensed with a power output "in excess of that necessary to render satisfactory service." (Section 4.636, FCC Rules and Regulations). The available RF channel width is 25 Mc.

This band also falls within the 6,425 - 7,200 Mc band proposed in Docket No. 13522 for earth-to-space transmission to communications satellites. It is proposed to share this band with existing earth communications. While certain technical factors may require consideration, this matter should not affect educational use of this band.

7,050 - 7,125 Mc

By recent allocation action (Docket No. 14729, July 12, 1963) this band has been attached to the 6,875 - 7,050 Mc band and all the Regulations of the latter now apply to it. The effect of this action was to remove common carrier reservations and to make the three 25 Mc channels available to broadcasters. These three channels are available for educational television interconnection in the same manner as those in the 6,875 - 7,050 Mc band.

12,200 - 12,700 Mc

This band is available to closed-circuit educational television operating under Business Radio Service Rules. The general comments applying to developmental and educational operation within the Industrial Radio Rules are applicable. Technical regulatory restrictions are a maximum RF bandwidth of 10 Mc and a maximum transmitter power of 5 watts.

12,700 - 13,200 Mc

This band is available for interconnection of broadcast material under the Auxiliary Broadcast Rules. Intercity relay is conditional to non-interference to TV pick-up and STL. The available channel widths are 25 Mc and power is limited to "that necessary to render satisfactory services."

13,200 - 13,250 Mc

This band is unusual in that it is available for interconnection of both broadcast and closed-circuit facilities. Broadcast material may be transmitted by stations licensed in the Auxiliary Broadcast Service, and closed-circuit material may be transmitted by stations licensed in the Business Radio Service. The possibility of obtaining "double licenses" i.e., a license in each service, for a single point on an interconnection network has not been explored. The regulated technical parameters for broadcast operation are 25 Mc channel width, and limitation of power to "that necessary to render satisfactory service." No technical factors are regulated in the interim technical standards of the Industrial Radio Rules. Both fixed and mobile operations are permitted under the Auxiliary Broadcast Rules, but only fixed operations are permitted with Business Radio Service authorizations.

PRESENT USAGE OF MICROWAVE FREQUENCIES

To complete an examination of available spectrum space, it is necessary to analyze the present usage. To do this several maps of the northeastern United States have been prepared and are included in Appendix D of this report as Figures A-1 through A-5. The northeastern states were chosen for examination because of the congested nature of present frequency assignments in this area. If methods developed in the following section of this report for determining available spectrum space are feasible for this area, then they should be directly applicable to the examination of other allocation situations.

Examination of these maps shows the difference between broadcast and industrial operations. The broadcast usages tend to be mobile operations concentrated in metropolitan areas while industrial operations are largely directional and do not generally concentrate at specific locations but saturate a wide area around an industrial center. Examples of this saturation tendency may be seen in the Pittsburgh area for the 6,575 - 6,875 Mc band and for the 12,200 - 12,700 Mc band in the New York City area.

Since the spectrum "fills up from the bottom" the density of operations decreased with an increase in frequency. Evidence of this is that a map for the 12,700 - 13,200 Mc band is not included because there was only one licensee, operating 50 mobile units, in the entire geographical area that was studied. The best indication of the tendency for operation density to decrease with frequency is a comparison between the 6,575 - 6,875 Mc and 12,200 - 12,700 Mc bands. The comparison is not exactly valid between the 1,990 - 2,110 Mc and 6,575 - 6,875 Mc bands because different channel-width assignments also affect the assignment distribution.

Finally the 2,500 - 2,690 Mc operations in this area are detailed in Figure A-2. Because of the recent allocation actions in Docket No. 14744, this band will be available for multiple-address instructional television fixed stations, and no new operational fixed systems will be authorized for a period of three years unless they meet the technical requirements for operation in this service. As a matter of interest there are presently eight licensees operating in the continental United States in this band within the Industrial Radio Rules. Five of these operations are in California, two are in the Southwest, and one is in Pennsylvania. In addition, several experimental stations operate in this band.

BACKGROUND OF FCC REGULATORY POLICIES AFFECTING EDUCATIONAL USE OF MICROWAVE FREQUENCIES

The Federal Communications Commission is an administrative agency of the federal government that was created by the Communications Act of 1934 to regulate wire and radio communications activities and to develop the utilization of radio frequencies in the public interest, convenience, and necessity. The Commission must, by statute, regulate transmission of radio energy used for communications and signaling within the jurisdiction of the United States. It accomplishes this by licensing the right to operate radio transmitters, and Rules and Regulations have been established to govern the granting of such licenses and the utilization of such transmitters.

It is important to recognize that FCC Rules and Regulations follow a pattern that was established to handle problems existing long before educational television was a subject of concern. Historically, the FCC has considered broadcast applications of radio as separate and distinct from other types of radio frequency use. The FCC has been careful to insure that those persons licensed to use broadcast channels operate their stations in the public interest as trustees of a public trust. In particular, facilities used for such purposes have been carefully regulated to insure that their use is responsive to the interests of the public being served, rather than serving the particular needs of the licensee. These broadcast channels are accorded protection from interference in keeping with the effort to provide for their maximum effectiveness.

Non-broadcast services regulated by the FCC are subject to a philosophy of regulation which is different from that developed for broadcast services. In general, these users are classified by the nature of their business, and must establish an eligibility based upon this classification and their needs. Once eligibility is established, a non-broadcast user has the right to apply for particular channels which have been assigned to his particular category of use. Usually, a sharing of channels is possible among those eligible; however, coordination between users is required to minimize interference resulting from this sharing of channels.

The FCC Rules are awkward for educational television in that some applications are for broadcast operations and others are for non-broadcast facilities. A new category of stations provided by the FCC to serve point to point instructional needs is under the broadcast portion of the FCC Rules; such facilities are not called broadcast stations but "instructional television fixed" stations.

Another indefinite area exists with regard to the need for using microwave network facilities to serve educational needs that sometimes involve broadcast stations and at other times, or at the same time, serve educational needs by interconnecting closed-circuit operations. Currently, the FCC Rules are not well suited to handling such a mixed usage. The Commission recognizes this and has rule makings in process looking toward a partial or interim solution of this problem. In the meantime, it will be necessary for those who are engineering educational television systems to explore carefully the alternative technical solutions to specific problems and to work out solutions to the extent possible within the existing Rules.

It is sufficient at this time to recognize that there is a distinction in the Rules between broadcast use and non-broadcast use of frequencies, and that this distinction results from an historical development of FCC philosophy rather than from considerations relative to educational television.

Summary of Pertinent Commission Actions

Docket No. 11866 was instituted by the Commission as a fact-finding hearing in November, 1956, for the purpose of reviewing allocation needs for frequency bands above

890 Mc. The results of this hearing are contained in a 64-page Report and Order dated August 6, 1959. None of the policies expressed therein concerned educational television per se, but opposition statements and other remarks filed by several parties shortly thereafter caused the Commission to re-examine certain issues and to issue a Memorandum Opinion and Order on October 5, 1960.

The investigation leading to the Report and Order was concerned entirely with microwave frequency allocation, and educational television interconnection was not specifically provided for until the further investigation leading to the Memorandum Opinion and Order. In this second order an exception to the FCC's previously developed policies was made for closed-circuit educational television interconnection systems. However, the policies expressed in the original Report and Order are nonetheless important because of their effect on usage of microwave frequencies for educational television interconnection. Specifically the policies developed by the FCC from testimony in this Docket would require that:

(1) Short range and local area communications should be accomplished on frequencies above 10,000 Mc.

(2) The common carriers and private users should not share frequency bands.

(3) Applicants for private point-to-point systems should furnish facts of intended operation to allow the FCC to avoid wasteful assignment of spectrum space.

(4) The Commission should not be required to establish regulations pertaining to interconnection of common carrier and private microwave systems.

(5) The Fixed and Mobile services should not share frequencies.

(6) The Commission should serve the public interest, convenience, and necessity rather than foster competition to improve the communications art.

(7) Equipment manufacture and development should benefit from the incentive of increased availability of frequency use.

In the subsequent Memorandum Opinion and Order of Docket No. 11866, attention was devoted to possible microwave spectrum requirements for interconnection of educational television facilities. In this proceeding the FCC stated that:

(1) It would be in the public interest to provide frequencies below 10,000 Mc for intercity ETV relay;

(2) Short range operations should utilize frequencies above 10,000 Mc;

(3) Applicants for intercity ETV microwave licenses in the operational fixed (Industrial) services should furnish data showing, apart from economic reasons, why it is not feasible to operate above 10,000 Mc;

(4) The band 6,575 - 6,875 Mc should be appropriate for intercity closed-circuit television.

Instructional Television Fixed Service

As a result of the Instructional Television Fixed Service, interest has recently been focused on the 2,500-2,690 Mc band. In this instance, the Notice of Proposed Rule making (December 12, 1962) suggested that new multiple-address service, utilizing "educational television fixed stations," be established and that such stations might be used for interconnecting purposes. The Report and Order (July 30, 1963), however, restricts such usage to the local exchange of material and precludes relaying of material between separated distribution systems. Thus, this action removes the 2,500 - 2,690 Mc band from possible usage for high quality interconnection of educational television facilities.

In particular, Docket No. 14744* establishes an "Instructional Television Fixed" class of station for use by publicly supported or otherwise eligible private educational organizations. Transmissions from these stations are to be directed primarily to specific locations equipped with appropriate receivers. The channels provided for such operations are available within the structure of the Auxiliary Broadcast Rules.

From these observations it would appear that it is possible to operate closed-circuit educational television distribution systems in this band. Furthermore, such stations may be licensed to obtain and deliver instructional material at "nearby terminals or connection points of closed circuit educational television systems."** The possibility of licensing closed-circuit distribution facilities in this new service needs to be clarified.

It is important to note a new concept that has appeared in this proceeding – a concept that has not appeared before in the Rules and Regulations of the Commission. Until recently, educational television has been viewed by the Commission as operating in either the broadcast or closed-circuit (non-broadcast) manner. Largely, this is because the established Rules of the Commission prohibit radio facilities authorized under the Industrial Radio Rules from transmitting material intended for use in connection with broadcasting,† and Broadcast Auxiliary facilites are prohibited from transmitting material which are not intended for broadcast,†† Interconnection networks might be licensed within either the Auxiliary Broadcast Rules or the Industrial Radio Rules, but the material transmitted over them might not always be interchanged.

Dockets No. 14744 and 14894 do, however, provide for certain exceptions to the previous Rules concerning interchange of educational television material, and these actions indicate that the Commission is giving consideration to the concept of sharing between broadcast and non-broadcast educational television facilities.

To summarize, there are two aspects of the regulatory problem which are of importance to the educator. The first is concerned with the existing regulatory - allocation situation and the limitations it imposes on interconnecting educational television facilities. The second is concerned with what is being done to change and alleviate the existing situation. This latter concern is further subdivided into: (1) consideration of existing proposed rule amendments, and (2) the conflicts that result.

First, the interconnection of broadcast educational television facilities is restricted by the shared nature of its service. Both mobile and fixed facilities are permitted to operate simultaneously on the same channel. Studio-to-transmitter link assignments are made on an exclusive basis. This exclusive allocation procedure contributes to frequency crowding in metropolitan areas, and the sharing of mobile and fixed operation increases possible interference to high-quality interconnection networks. The presently authorized 25 Mc channel bandwidth should not be a factor in restricting high quality interconnection, although it will limit the amount of additional information that can be relayed.

Second, the interconnection of closed-circuit educational television facilities is also restricted by a sharing arrangement, but the sharing is on a different basis. That is, microwave frequencies are shared among fixed stations in the several operational services within the Industrial Radio Services. While all users must operate with developmental authorizations, educational television intercity relay networks are further held responsible for proving that operation above 10,000 Mc would not be feasible. This responsibility could be a serious obstacle to the development of closed-circuit interconnection networks. In addition, there is a serious problem as to RF channel widths authorized in the Industrial Service. The industrial bands are subdivided into 10 Mc channels, but a 10 Mc channel is not wide enough to handle interconnection of even a 525-line television signal.

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*Docket No. 14744, Page 16, Report and Order, July 30, 1963.

**Section 4.931(d), FCC Rules and Regulations.

† Section 11.2, FCC Rules and Regulations.

†† Section 4.631, FCC Rules and Regulations.

While there is a possibility that two adjacent 10 Mc channels could be assigned for use as a single interconnection channel, further specific proof of need would be necessary on a case-by-case basis. Accommodation of educational television in the industrial bands will require attention to the need for different channel widths and to the best arrangement for the sharing of channels.

Present regulations also affect full utilization of educational television frequencies by restricting the types of material that may be transmitted over a given facility. For example, as the Rules presently exist (June, 1964) there is no provision for transmission of both broadcast and closed-circuit material over the same facilities. This seriously affects the possible flexibility of an educational interconnection network. Therefore, the FCC Rules currently prevent microwave interconnection of broadcast and closed-circuit educational television centers on the same system. This distinction exists because of the traditional development of the FCC Rules and Regulations and because of the unique interconnection needs of educational television.

Several changes to the present situation are currently (June, 1964) in the Petition for Rule Amendment stage at the FCC. In all cases the deadline for filing comments has passed. The restriction between types of information that can be transmitted by a station licensed in a given service is under consideration in Docket No. 14894. In this action it is proposed to amend the Rules of the Commission to permit a broadcast television pick-up, STL, or intercity relay to transmit program material to non-broadcast educational television facilities, and closed-circuit stations licensed in the Business Radio Service to transmit program material to non-commercial educational television broadcast stations. This alternative channel use may not, however, constitute more than 20% of the total facility use during any one license period, and no charge will be able to be made for the use of the auxiliary broadcast facilities.

This action is a step in the right direction but is not the solution to the basic problem. Full utilization of educational television requires that there be legal authorization to exchange information at will.

Docket No. 14896 resulted from a petition to make the 1,850 - 1,990 Mc band of frequencies available for interconnection of broadcast and non-broadcast educational television facilities. In brief, this request was denied, but the Commission does propose to include the 1,850 - 1,990 Mc band in the Business Radio Rules and thereby make it available for closed-circuit television use. This proposal does not satisfy the intent of the original petition, but might provide additional spectrum space for educational television interconnection. The interim maximum bandwidth for this band, however, is 8 Mc, and is too narrow for interconnection of anything but low quality television.

Further rule amendments affecting the spectrum space which might possibly be available for educational television interconnection are concerned with the sharing of several frequency bands with communications satellites. These possibilities are too premature to be properly evaluated at this time.

What must be emphasized with respect to education is that requirements can only be properly satisfactory if operational and technical needs are defined and appropriate modification is made in regulatory procedures to enable these needs to be met. It is particularly important that educators and their technical advisors understand the complex nature of this problem, and realize that whatever solutions are proposed to meet varying educational needs should be based on technical facts that relate these needs to the possibilities which exist for meeting them.

V

An Application of the Computer Program to the Selection of Microwave Channels

SELECTION OF A SAMPLE PROBLEM

In order to specify the technical characteristics of microwave networks appropriate for the interconnection of educational television systems, a sample interconnection problem illustrating typical requirements will be considered. The presentation of this sample problem will consider the selection of the network routing and sites, the preliminary calculations, and the selection of frequencies and channels to be used. The results of the digital computer program described in Appendix C will be applied to the frequency selection problem.

While the actual interconnection system might be developed in any geographical area, the system used as an example is routed through several of the eastern mid-Atlantic states. The route is developed within this area in order to study the characteristics and conditions that exist in an area which exhibits congested microwave traffic. If satisfactory, the method for studying of this area could then reasonably be projected into a national pattern. Further, by examining an area that is presently congested, the results of the study might be projected as a possible future allocation pattern for other areas. In any event, the digital computer techniques can be applied to any set of interconnection requirements simply by applying the appropriate input data. In this respect the sample system characteristics merely provide a definition of the individual geographical areas required for the computer calculations.

The route chosen for the sample interconnection system, Figure 11, is from Baltimore to New York City, passing through Philadelphia. A branch, or spur, also extends westward

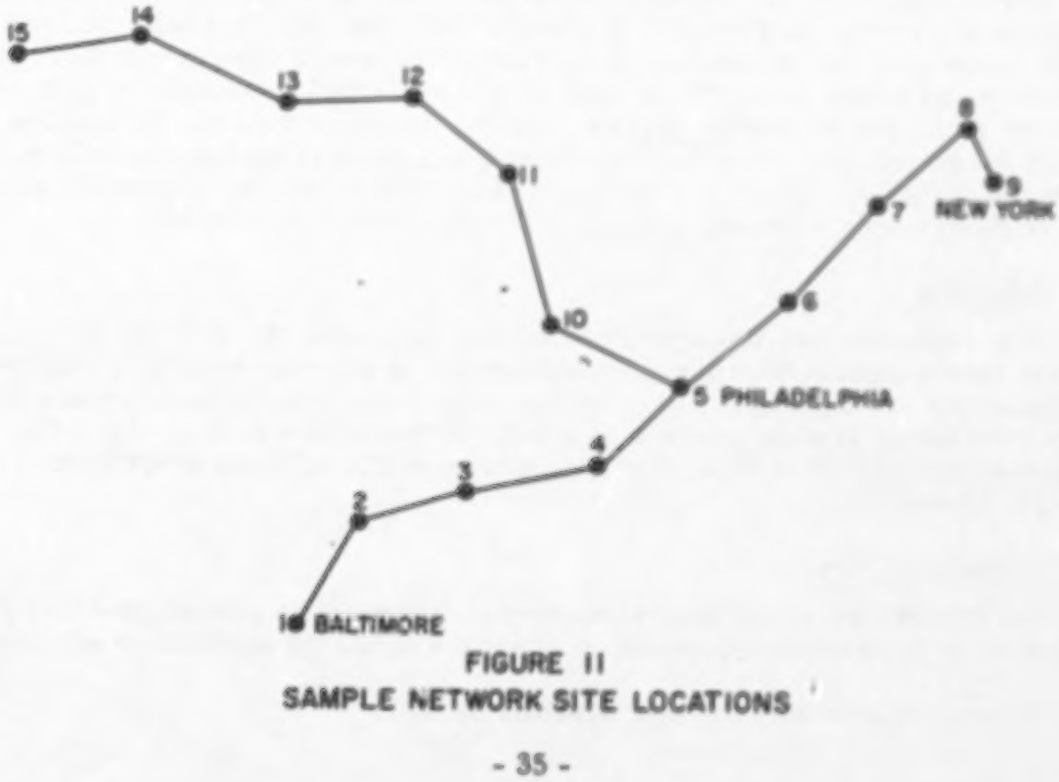

FIGURE 11
SAMPLE NETWORK SITE LOCATIONS

from Philadelphia. The spur was included in the sample system to (1) provide a radial situation in the computer consideration, and (2) to provide an example of microwave allocation density in rural areas for comparison with the allocation density of the three metropolitan areas.

CHOICE OF TECHNICAL REQUIREMENTS FOR THE PROBLEM

The requirements for this problem were chosen in the form of technical specifications that would be developed from the definition of requirements made by the users of the interconnection system. A set of such requirements was selected for the sample system and preliminary calculations were made to determine the feasibility of the system. The interconnection system is then used as a framework for the selection of frequencies identified in the computer program results.

1. Routing and Sites

The actual network routing was developed by a topographic map study. The repeater sites were chosen on a topographic basis at distances of 25 to 30 miles. In most cases these sites were determined on the simple basis of available high terrain necessary to secure the chosen fresnel-zone clearances along the path. The shortest hop in the hypothetical system is 20.7 miles and the longest is 30 miles.

2. Choice of Frequency Band

Bandwidth allocations, available transmitter power, antenna gain, and lack of significant attenuation due to rain make the 6,000 - 7,000 Mc frequencies a good choice for use in long-haul microwave networks. The frequency bands in this region of the spectrum that are available to educational television for interconnection are 6,575 to 6,875 Mc and 6,875 to 7,125 Mc. The frequency 6,800 Mc will be chosen as the frequency for preliminary calculations, but cognizance will be taken of possible operations in the 2,000 and 12,000 Mc bands.

3. Tower Heights

Tower heights at the repeater sites are selected to achieve the chosen fresnel clearance at all points along the propagation path. Fresnel zone clearance for the 6,000 - 7,000 Mc frequencies can be obtained in each hop of the sample system with tower heights of 150 feet. An additional safety factor of 50 feet, to allow for trees and/or buildings in the propagation path, would require 200-foot towers. If use of the 2,000 Mc frequencies is desired or necessary, greater tower heights will be necessary because the fresnel radius is greater at the lower frequency. Conversely, use of the 12,000 Mc frequencies would allow use of shorter towers because of reduced fresnel radius requirements.

4. Reliability

Both equipment and propagation reliability determine the over-all system reliability. The fade margin is determined from the chosen propagation reliability objective and is dependent upon the hop length. The reliability objective established here for sample preliminary calculations is maintenance of an acceptable[*] picture for 99.9 per cent of the time. The fade margin required to attain this reliability for a 27.5 mile hop at 6,800 Mc is 28 db. (Figure 21, Appendix B).

5. Transmitter Power

The transmitter power used in microwave transmission systems is set by system requirements or by available equipment. Five watts, which is the maximum power available within the state-of-the-art for 6,800 Mc equipment, will be used for preliminary calculations. These calculations may show that a lesser power will satisfy network requirements or that the hop lengths must be reduced in order to provide the performance objective.

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[*] Signal-to-noise ratio of 26-42 db (See Appendix B).

6. Antenna Size

The antenna size is determined by the gain required for desired system performance. The gain of a parabolic antenna increases with frequency and antenna diameter while the beamwidth decreases. The desire to maintain a beamwidth of at least one degree limits antenna gain to a maximum of 44 db.

7. Excess Signal-to-Noise

The distortion and noise of a microwave signal increases with the number of repeaters through which the signal travels. Intermodulation and harmonic distortion are not easy to estimate, but random noise for identical hops is considered to increase simply as $10 \log_{10} N$ where N is the number of identical hops. The amount of received signal present above that actually required for satisfactory communications over a one-hop path may be termed the excess signal-to-noise or excess fade margin, since excess signal-to-noise ratio is equal to excess fade margin. This value can be used to predict how much fading can be tolerated before the received signal becomes unusable due to excessive noise content. Alternatively, the excess signal-to-noise may be interpreted as an indication of the number of identical hops a microwave relay system may be extended while achieving an overall signal-to-noise ratio no worse than the original "one-hop" link.

8. Preliminary Calculations

Table VI presents these calculations for the frequency 6,800 Mc. Since two eight foot antennas on each path will theoretically provide the necessary network gain with a 1.3 degree beamwidth, the network design is considered satisfactory.

TABLE VI
PRELIMINARY CALCULATIONS — 6,800 MC

Item	Value	Explanation
1. System Losses		
a. Path attenuation (27.5 mi.)	142.0 db	
b. Wave guide and reflections	2.5 db	
c. Aging and Misc.	3.0 db	
d. Total system loss	147.5 db	
2. Thermal Noise	-129.2 dbw	KTB for B = 30 Mc
3. Noise Figure	12.0 db	
4. Receiver Noise Level	-117.2 dbw	
5. Receiver Threshold	-105.2 dbw	(See Note 1)
6. System Gains		
a. Transmitter Power	7 dbw	(5 watts)
b. Antenna Gain	84 db	($G_R + G_T$)
c. Total System Gain	91 dbw	
7. Received Signal Power	- 56.5 dbw	(91 dbw - 147.5 db)
8. Fade Margin (FM)	48.7 db	(105.2 db - 56.5 dbw)
9. Excess Fade Margin (or signal-to-noise)	20.7 db	(48.7 db - 28 db)
10. Total No. of Identical Hops	100 hops	N = Anti Log $\left(\frac{\text{excess FM}}{10 \quad 10}\right)$

1) Receiver Threshold: Input signal level required to produce an output video s/n of 26 db. This is -105.2 dbw for a typical 6,800 Mc Receiver.

If this system were to be implemented, further calculations could be undertaken to optimize the system and perhaps eliminate a repeater. These preliminary calculations could consider possible operations in the three different frequency areas available for educational television interconnection. A field survey would then be undertaken to investigate the chosen sites and paths in order to verify the tree heights and other obstructions not shown on the topographical charts. Since only a sample situation is being considered and preliminary calculations for the 6,575 - 7,050 Mc band demonstrates that the network design is feasible, these steps have been omitted in this example.

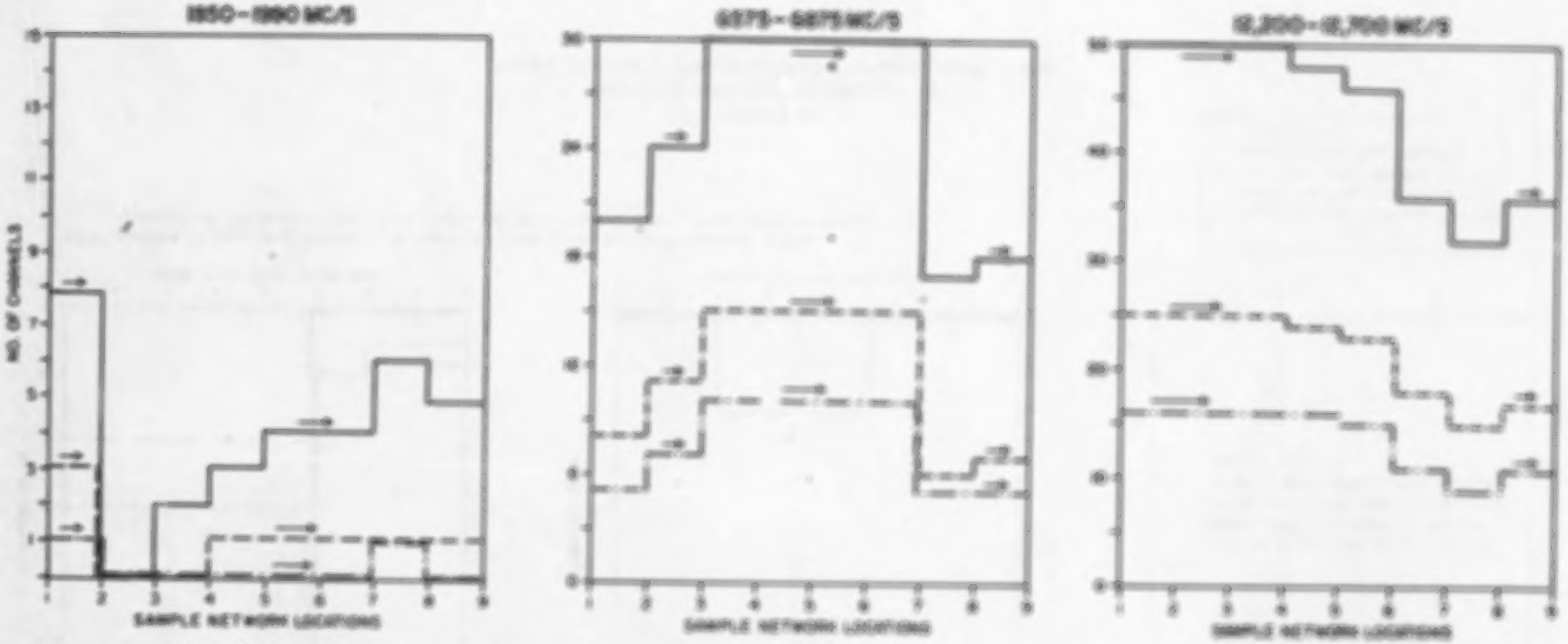
A DETERMINATION OF MICROWAVE FREQUENCIES AND CHANNELS

The specific frequencies for the system transmitters must be determined for final calculations, to secure licenses, and to order equipment. These frequencies would be based upon a survey of the frequencies in use in the geographical area involved. For the purposes of this example, however, it is assumed that conservation of spectrum space is of concern. Consideration of this factor is of particular interest here because the computer is programmed to indicate efficiency of spectrum usage in the process of identifying frequencies for use in a network.

Identification of microwave channels can be accomplished by comparing available spectrum areas for transmission with the available areas for reception between two adjacent interconnection points. This technique is described in Appendix C. Figures 14 and 15 are included for application of this consideration to the 6,575 - 6,875 Mc Industrial band and to the 6,875 - 7,050 Mc Auxiliary Broadcast band.

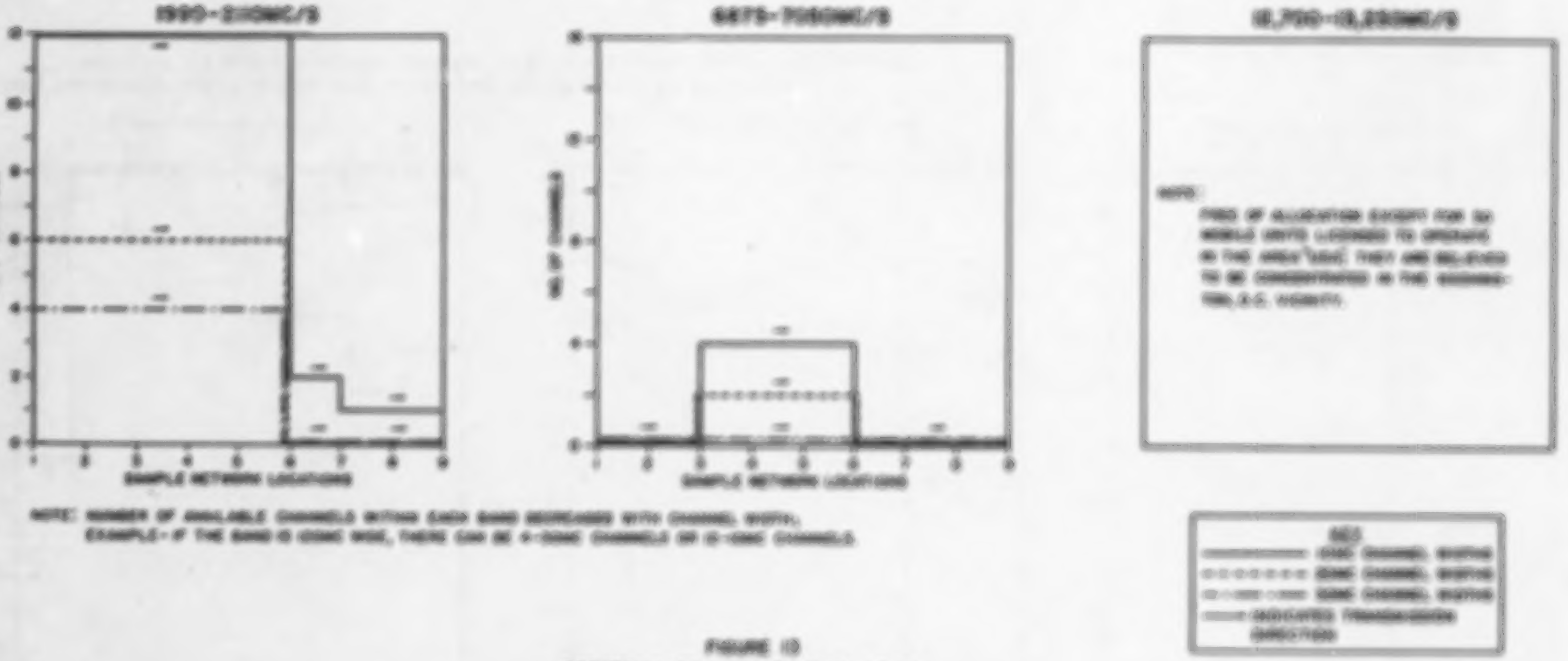
With the allocation situation described in Figure 14, it would be relatively easy to select efficient channels for a single channel simplex (one-way) system by using unassigned transmitting frequencies which are coincident with either "usable assigned" or a combination of "usable assigned and unassigned" receiving frequencies. Use of these channels is efficient because such channels are within spectrum space which would not be used at the particular geographic location of the sample network sites if only unassigned spectrum space were considered. Therefore, use of these channels also makes it possible to leave more spectrum space available for subsequent use.

As the number of required channels increases, however, other factors of channel selection become more important than spectrum conservation. An example of what can be considered to be a stringent requirement on this particular spectrum space is established by analyzing Figures 12 and 14. The results of this process are tabulated in Table VII. This example considers a simplex system of three channels, each having a 20 Mc width.



NOTE: NUMBER OF AVAILABLE CHANNELS WITHIN EACH BAND DECREASES WITH CHANNEL WIDTH;
EXAMPLE – IF THE BAND IS 120MC WIDE, THERE CAN BE 4 – 30MC CHANNELS OR 12 – 10MC CHANNELS.

FIGURE 12
SPECTRUM AVAILABILITY EVALUATION
(BANDS AVAILABLE FOR CLOSED–CIRCUIT ETV INTERCONNECTION)



NOTE: FREE OF ALLOCATION EXCEPT FOR 50 MOBILE UNITS LICENSED TO OPERATE IN THE AREA. THEY ARE BELIEVED TO BE CONCENTRATED IN THE WASHINGTON, D.C. VICINITY.

NOTE: NUMBER OF AVAILABLE CHANNELS WITHIN EACH BAND DECREASES WITH CHANNEL WIDTH. EXAMPLE - IF THE BAND IS 100MC WIDE, THERE CAN BE 4-25MC CHANNELS OR 10-10MC CHANNELS.

FIGURE 10
SPECTRUM AVAILABILITY EVALUATION
(BANDS AVAILABLE FOR BROADCAST ETV INTERCONNECTIONS)

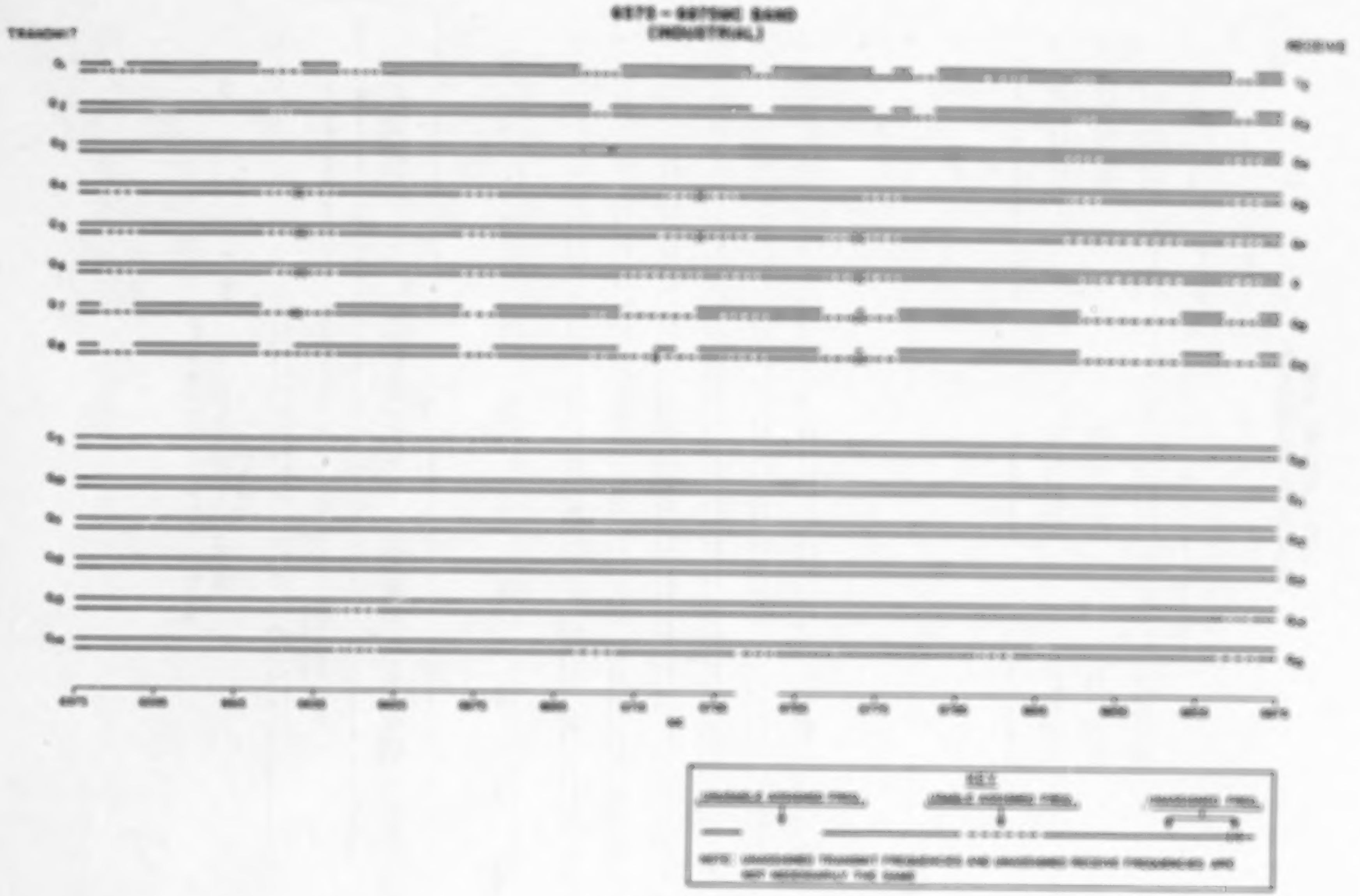
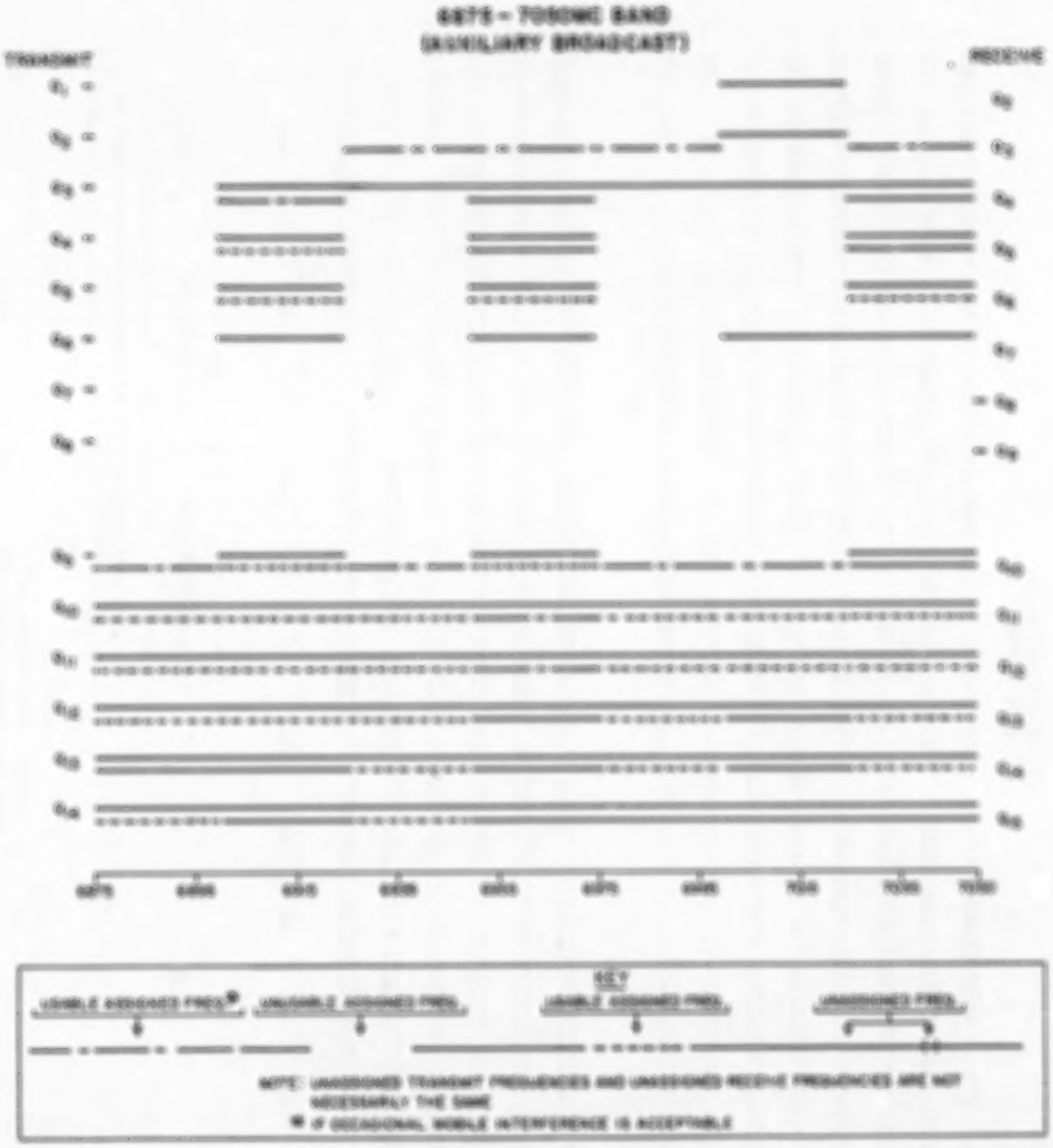


FIGURE 14
GRAPHIC PRESENTATION OF
USABLE NETWORK FREQUENCIES



NOTE: UNASSIGNED TRANSMIT FREQUENCIES AND UNASSIGNED RECEIVE FREQUENCIES ARE NOT NECESSARILY THE SAME

* IF OCCASIONAL MOBILE INTERFERENCE IS ACCEPTABLE

FIGURE 15
GRAPHIC PRESENTATION OF
USABLE NETWORK FREQUENCIES

TABLE VII

CHANNEL AVAILABILITY FOR THE 6575 - 6875 INDUSTRIAL BAND

Interconnection Points From	To	Center Frequencies of Selected Channels (Mc)	Notes
1	2	6596.6, 6690.0, 6797.4	1, 2
2	3	6640.0, 6762.6, 6852.6	3
3	4	6585.0, 6700.9, 6795.0	4
4	5	6740.9, 6700.9, 6865.0	
5	6	6585.0, 6730.9, 6815.0	5
6	7	6660.9, 6770.9, 6865.0	
7	8	6605.0, 6770.9, 6815.0	
8	9	6660.9, 6750.9, ------	
5	10	6605.0, 6700.9, 6815.0	6
10	11	6652.0, 6757.0, 6865.0	
11	12	6585.0, 6700.9, 6815.0	
12	13	6652.0, 6757.0, 6865.0	
13	14	6585.0, 6700.9, 6815.0	
14	15	6652.0, 6757.9, 6865.0	

Referring to the notes of Table VII:

1. For two of the three channels (6,596.6 Mc and 6,797.4 Mc) it is possible to use a combination of "usable assigned" and "unassigned" receiving frequencies.

2. The channels are selected as far apart as possible to prevent adjacent channel interference in the system. Adjacent channel carrier frequencies should be separated by at least three times the highest modulating frequency to avoid interchannel interference. There should also be at least a 40 to 50 Mc separation between received channels because practical receiver filters cannot reject a closely spaced adjacent channel. The use of dual polarized antennas might alleviate the receiver filter problem.

3. The transmit frequencies at this point are offset from the receiving frequencies for the same reasons as in (2) and also because economical parabolic antennas do not provide sufficient isolation between receive and transmit antenna mounted on the same towers. The required isolation between receiver and transmitter energies is impossible to achieve when passive reflectors are used.

4. The chosen transmit frequencies at this network point are virtually the same as those used at interconnection point 1. They can be used because they will not interfere with the receivers at point 2 and because over-reach interference at the point 4 receivers from the point 1 transmitters is not likely.

5. When selecting the channels for transmission from interconnection point 5 to point 6, consideration of interference leads to the observation that the selected sites for relay points 4 through 8 are located within a few degrees of a straight line. This means that "over-shoot" interference is possible. This problem is usually avoided in proper system design by offsetting the interconnection points from a straight line, but it occurs in this sample network because the sites were selected largely on the basis of available high terrain. In this individual example of frequency selection, caution must be observed in selecting interconnection channels between points 4 and 8. Cross polarization of antennas transmitting on identical channels at different interconnection points will be necessary.

6. In selecting frequencies for transmitting from point 5 to point 10, the receiving frequencies at point 5 must be avoided. It is possible, however, to utilize the point 5 to point 6 transmit channels for transmitting to point 10 because of the directive nature of parabolic antennas and cross-polarization techniques which will permit sufficient isolation. All three of the selected channels are chosen on the basis of those two factors.

Evaluation of the results shows that there is sufficient spectrum space available in the 6,575 - 6,875 Mc band to provide one-way multiple channel transmission of information for the chosen sample system. However, sufficient space is probably not available for easy provision of the channels necessary for duplex (two-way) operations. Three alternatives can be investigated to identify additional channels. These alternatives are:

1. Reroute the system to provide definite offsets in transmission paths between points 4 and 8.
2. Utilize frequencies from the 2,000 Mc or 12,000 Mc Industrial bands.
3. Utilize the same three frequencies for transmission in each direction from one interconnection point.

The first alternative is difficult because of the type of terrain between the end and switching points. The second alternative is possible, but might also require a redesign of the routing to provide sufficient system reliability. Alternative three might provide some of the additional required channels, but it is doubtful that all channel requirements could be met, and furthermore, it would require special antenna techniques to avoid interference.

Another example of selecting channels can be developed for the 6,875 - 7,050 Mc Auxiliary Broadcast band, but one additional consideration must be made. In the previous example for the Industrial band, all the stations were fixed. The Auxiliary Broadcast band is different in that both mobile and fixed operations may occur on the same channel.

Co-channel mobile operations make it difficult to establish channels for a fixed, high quality network because the interference possibilities are difficult to predict. For the purposes of this example it was decided to consider possible mobile interference separately. This separation has been accomplished insofar as possible, and the results are shown in Figure 15. There is a fourth category of spectrum space established to describe spectrum space which might be usable in a high-quality network if occasional interference from mobile operations is acceptable. This category is represented in the figure by an alternating dot-dash code.

It is apparent that there is not sufficient spectrum space available in this band for even a single interconnection network. There are no channels available for transmission from network points 1 to 2, 2 to 3, 6 to 7, 7 to 8, and 8 to 9. There are some channels available at the stations between 3 and 6, but their use would have to be on an alternate basis between the separate transmitting points. For interconnection points 10 through 15, which are mostly in rural areas, the availability situation becomes much better. A channel selection can be made for this leg of the network in the same manner used in the previous example.

Since frequencies are not available at five interconnection points, an alternative solution will be necessary. An examination of the 1,990 - 2,110 Mc band shows that several channels would be available in this band for network use. Twenty-five Mc channels would provide the necessary channels for this example, but it would be an unrealistic solution because the Rules and Regulations of the FCC provide only 17 Mc channels in this band. It therefore seems likely that channels must be selected from the 12,700 - 13,200 Mc band to complete the development of this interconnection network. Adequate quality of transmission cannot, however, be obtained if such channels are used on a large scale in the sample network. This can be seen by the values calculated in the following Table.

TABLE VIII

PRELIMINARY CALCULATIONS - 13,200 MC

Item	Value (db)	Explanation
1. System Losses:		
a. Path Attenuation (27.5 mi.)	147.8 db	
b. Wave Guide and Reflections	4.0 db	
c. Aging and Misc	3.0 db	
d. Rain Attenuation	3.0 db	
e. Total System Loss	157.8 db	
2. Thermal Noise	-129.2 dbw	
3. Noise Figure	14.0 db	
4. Receiver Noise Level	-115.2 dbw	
5. Receiver Threshold	-103.2 dbw	
6. System Gains:		
a. Transmitter Power	- 3 dbw	(0.5 watts)
b. Antenna Gain	88 db	($G_R + G_T$)
c. Total System Gain	85 dbw	
7. Received Signal Power	- 72.8 dbw	(85 dbw - 157.8 db)
8. Fade Margin (FM)	31.4 db	(103.2 dbw - 72.8 dbw)
9. Excess Fade Margin (or signal-to-noise)	2.4 db	(31.4 db - 29 db)
10. Maximum No. of Identical Hops	1 Hop	(N = 1.7)

These calculations indicate that it might be possible to use channels from the 12,700 - 13,200 Mc band on a maximum of one long or two short hops within the system. If it were necessary to utilize more than two such channels and maintain a 99.9% propagational reliability, the routing would have to be re-examined for possibilities of shorter or offset hops.

ANALYSIS OF RESULTS

A closed-circuit, three channel, (30 Mc), one-way interconnection system which utilizes frequencies from the 6,000 Mc Industrial band is feasible. A three-channel duplex operation, however, might require utilization of some frequencies from other bands while a two-channel (20 Mc) duplex operation probably would not.

The difficulty of providing channels, even when such a relatively uncrowded band as the 6,000 Mc Industrial band is considered, suggests that the system routing can be optimized. One possible solution would utilize less favorable terrain to provide greater path offsets and closer repeater spacings. The economics of such a solution would, of course, have to be compared with the cost of providing the network.

Establishment of a network for exchange of the broadcast type of television would be difficult for the particular route and geographical area inspected. It would be possible to develop a network by utilizing channels from the different spectrum bands available for broadcast interconnection, but greater cost would be involved because of the probable network redesign. This, in itself, is an indication of the degree of difficulty that will be experienced in developing broadcast interconnection networks between metropolitan areas.

In summary, regulatory factors were set aside to a large extent in this interconnection problem because the concern was with the technical factors involved in providing interconnection. Development of a specific system was not the object of this investigation. Rather it was undertaken to provide an example of the problems involved and the techniques used in microwave channel selection. These techniques utilized the results of the digital computer program and provided an example of the value of a general approach to the over-all spectrum evaluation.

While the situation to which the techniques were applied is somewhat more difficult than would typically be expected, the computer results and the techniques of utilizing them are an indication that regulatory factors can be included in the future selection of microwave channels.

APPENDIX A

Scanning and Reproduction of a Television Picture

Television, like photography, is a technique of "recording" information at a specific time and place for consequent "showing" at other times and places. The "information" is usually a picture of a scene or object, but it may also be a picture of printed material or of a temporal phenomenon. Both television and photography utilize a picture as an input, transform it to an intermediate form for transferral or storage, and then recreate the original picture on appropriate display screens. The intent of both is a clear and accurate reproduction of the original image, as "seen" by a camera; they vary only in the technique used to achieve that objective.

Photography is essentially a chemical process which is completed in a series of progressive steps. Each step deals with the complete picture image and each step results in a physical record of the image which is essentially permanent. While the product of each step (whether it be exposed film, developed negative, or paper print) may not be instantly usable, it is permanently recorded and conversion to a usable form is possible.

The television process is electronic and deals only with small elements of the complete image at any instant of time. A television picture is created on a television receiver screen by a process that can be compared to the painting of a picture by an artist. The picture of the complete scene image is constructed piece-by-piece on the receiver screen. Although the construction proceeds rapidly enough to complete each picture before the eye can perceive the construction, television is a time-varying process and does not usually result in a permanent physical record of each picture.

Television is further related to the photographic process by the manner in which motion is "recorded" and "shown." Motion is "created" in both the television and motion picture process by a rapid sequencing of pictures, or "frames," each of which is slightly different from the adjacent. The pictures of each process are constructed by different techniques, but the manner in which they portray motion is the same.

SCANNING AND SYNCHRONIZATION

When a camera, whether it be film or television, views a scene, a complete image of that scene is focused on a photosensitive surface. In the photographic process the surface is a film; in the television process the surface is the "target" of an electronic camera tube. In photography the progression from the exposure of the film in the camera to the "showing" of the picture on a screen or piece of photographic paper takes place in a number of separate steps, each of which deals with the complete scene image. In the television process, however, the progression from the exposure to the showing of the recorded image takes a different form. A complete scene image is focused and recorded on a photoconductive "target" in the camera tube, but the complete image does not progress instantaneously beyond this point. The recorded image is treated rather as a series of separate picture elements, each of which receives individual treatment.

Since television is an electrical process and since an electrical transmission circuit cannot carry more than one element of information at a single time, the separate picture elements must be sent at separate times, in sequence. The necessity to treat the scene image as a number of separate elements and to send those elements over an electrical circuit at different times (i.e., sequentially rather than instantaneously) is accomplished by "scanning" the image on the photosensitive target with a beam of electrons. The intensity of the beam of electrons is varied, or "modulated," by the intensity of the elements of light on the camera tube target, and a varying electrical signal is produced. This electrical television signal then controls the intensity of the electron beam which produces the series of visible spots which constitute the complete picture on the television receiver screen.

Since a scanning process is used to "examine" sequentially the television image on the camera target, some orderly scanning pattern must be used. It is necessary, in fact, to do so because the scanning patterns at both the television camera and receiver must be identical if the television receiver picture is to duplicate the original scene. There are a number of pattern possibilities, but the one that has come into nearly universal use is a pattern somewhat like the pattern followed by the eyes in reading a book. In this pattern the electron beam scans from left to right and from top to bottom in a manner which produces a large number of closely spaced horizontal "scanning lines" between the top and the bottom of the television picture.

Furthermore, an "alternate-line" scanning pattern has been adopted as a standard which in effect doubles the "flicker rate" and thus effectively eliminates flickering of the reproduced image. This technique is known as 2:1 interlace and is simply a technique of scanning every other horizontal line until the image is completely scanned, then returning the scanning beam to the top of the image to scan the remaining lines. Such a "half-scan" is referred to as a field and a complete picture scan (all lines scanned) is referred to as a frame. Thus each complete frame consists of two fields.

It is interesting to note that doubling the frame rate from 30 frames per second to 60 frames per second without using the 2:1 interlace technique would double the video bandwidth requirement. The 60 interlaced "fields" accomplishes the same thing with no bandwidth increase. This achievement is a classic example of imaginative engineering.

In figure 16a* the solid lines of the path represent the horizontal scanning lines and the dashed lines represent the path of the electron beam during the time that the visible spot is "blanked-out" and returned to the left side of the picture to start a new scanning line. The visible, or scanned, lines are inclined slightly downward because the electron beam is being moved simultaneously horizontally and downward across the picture. The downward rate is slower than the horizontal rate, which causes the visible scanning line to slope downward very slightly. This inclination can hardly be seen on a television receiver and is of no special significance. The invisible portion of the path (represented by the dashed lines) is nearly horizontal because the electron beam velocity from right to left is much higher than either the left to right or downward velocities.

The scanning motion continues to trace out every other line until the bottom of the television frame is reached, at which point the spot is once again blanked out and rapidly returned to the top of the frame. The spot then becomes visible again, and the second field is traced out between the lines of the first field. The two combined fields represent one complete television picture.

With such an involved scanning pattern it would seem difficult to maintain the correct relationships between fields and scanning lines. Inexact placement of the scan lines of two successive fields, for instance, can result in poor interlace, as in Figure 16b. Poor interlace will consequently cause the picture to exhibit lower effective vertical resolution. This possibility is reduced by applying a series of "equalizing" pulses preceding and following

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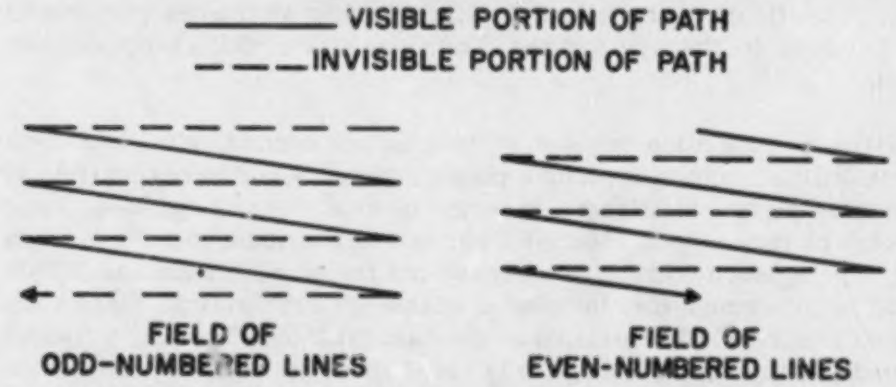
*See also, D. G. Fink, Television Engineering, 2nd Edition, New York: McGraw-Hill, 1952, pp. 9-12, 34-36.


(a.)
APPROXIMATE TELEVISION SCANNING PATHS

VISIBLE PORTION OF PATH
INVISIBLE PORTION OF PATH
FIELD OF ODD-NUMBERED LINES
FIELD OF EVEN-NUMBERED LINES

PATHS TRACED BY SCANNING SPOT DURING ALTERNATE FIELDS TO PRODUCE A SINGLE TELEVISION FRAME WITH 2:1 INTERLACE

(b.)
RESULTING INTERLACE POSSIBILITIES

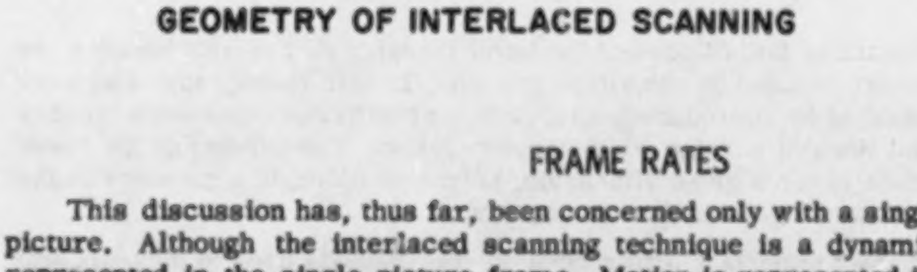


FIGURE 16

GEOMETRY OF INTERLACED SCANNING

the vertical synchronizing pulses. These pulses insure that the camera and receiver scanning patterns are identical insofar as proper interlace occurs in both patterns.

The vertical synchronization signals move the scanning beam up and down the screen at the necessary rate and, in combination with the horizontal synchronization signals, control the interlace by determining the exact time and place at which each scan line starts. In reality, the synchronization signals are the most important part of a television signal because they control the way in which the electrical picture signals are generated and utilized. If they are not present, there is little likihood that a steady television picture will appear on the receiver screen for anything but a fleeting instant.

FRAME RATES

This discussion has, thus far, been concerned only with a single, stationary television picture. Although the interlaced scanning technique is a dynamic process, no motion is represented in the single picture frame. Motion is represented in television in the same manner as it is in motion pictures; i.e., by showing a number of still frames in rapid succession. If each frame is slightly different than the preceding frame and if they occur rapidly enough, the eye will perceive smooth motion, due to the well known "persistence of vision" phenomenon.

If the repetition of still frames occurs at a high enough rate the sensation of light carries over from one picture to the next and the viewer's mind does not perceive that, in fact, separate pictures have been shown. But, if the repetition rate is not high enough, or if the image is too bright, the eye perceives the presentation of adjacent frames and is conscious of an annoying flicker sensation.

The motion picture industry has established a standard frame repetition rate of 24 frames per second. This repetition rate represents an economic compromise between adequate representation of motion and film length, but is not, however, high enough to completely avoid the flicker sensation.* This sensation has been avoided in motion picture projection by interrupting the projected light for a very short time during the time that each frame is being shown. This effectively doubles the flicker rate to 48 frames per second and makes flicker imperceivable to the eye for the conditions under which large-screen motion pictures are shown.

Television utilizes a frame repetition rate of 30 frames per second. While this is a higher frame rate than that utilized in motion picture photography, flicker is perceptible at this rate because the television picture is brighter, in terms of total image brightness, than the picture on a large motion picture screen. Since flicker is more evident to the eye when bright images are viewed, it is, again, desirable to increase the frame repetition rate. This has been achieved by, and is the reason for, interlaced scanning in television. Since each television field is completed in one-half the time that a television frame is visible, a flicker rate of 60 fields per second is achieved. Although only one-half of the picture information is actually present in each field of alternate lines, the eye can retain one field long enough to associate it with a successive field and thus "see" a whole picture without perceiving flicker.

The frame and field rate were chosen as 30 and 60 respectively in the United States for a number of reasons,** only one of which was elimination of flicker. The actual rates were chosen on the basis of the electrical power line frequency (60 cycles per second) used in the United States. In other parts of the world where the power systems operate on a frequency of 50 cycles per second, the chosen frame and field rates are 25 and 50 respectively. Flicker can be more obvious at these frequencies, but this is usually avoided by operating the receivers of such systems at lower image brightness levels than is customary in the United States.

PICTURE QUALITY

The performance of television as a visual process is described by the quality of the picture which it presents on the receiver or monitor. The terms by which television performance is described are thus the same that describe any visual image process – resolution and contrast. †

Resolution is the measure of faithfulness of the detail transfer that occurs between the original scene and the picture created by the visual process. In both photography and television, resolution is measured by reproducing a test chart or pattern containing a number of black and white parallel lines of varying width and separation. The number of the finest lines that can be discerned along a given dimension, height or width, is a measure of the degree to which fine detail can be seen in the visual picture.

There are, however, two important differences in the methods used to measure and specify the resolution of television and photographic systems. They are not fundamentally different, and are a result of historical development and convenience. Photographic film resolution is determined by counting the distinct parallel black lines on the photograph of a test chart.†† Each line on the chart is separated by a white space of a width equal to the black lines. In television, however, the total number of distinct parallel lines is counted, regardless of whether they are black or white. The latter method is more suitable for television because the number of lines of resolution in the vertical dimension corresponds to the number of visible scanning lines. It is also perhaps the most logical because the real element of concern in resolution determination is the total number of elemental details that can be discerned in a television image.

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*It would be possible to show more frames in a one-second period but greater lengths of film would be required.

**D. G. Fink, op. cit., p. 42.

†Motion is neglected here; it is assumed that the television field rate is such that the eye perceives smooth motion.

††D. G. Fink, op. cit., p. 25; see also H. A. Chinn, Television Broadcasting, First Edition, New York: McGraw-Hill, 1953, p. 391.

When assessing the resolution of a photographic process it is not necessary to consider the orientation of the parallel black lines in the picture, because the resolution is the same in every direction; however, in television the horizontal orientation of the scanning lines requires that the total picture resolution be considered in terms of both vertical resolution and horizontal resolution.

Vertical Resolution

The maximum vertical resolution of a television system is dependent upon the number of scanning lines in the scanning pattern. The actual vertical resolution, however, is always less than the total number of scanning lines. This occurs because some of the scanning lines are blanked out to provide time in the television signal for insertion of the synchronizing signal and also because not all of the remaining scanning lines can provide distinct resolution lines. Those scanning lines which remain after the synchronizing signal is inserted (and which therefore carry visible information) are known as the "active" scanning lines. Not even all of these lines are "effective" resolution lines because the scanning lines do have a finite width and misregistration of them with elements in the original scene prevents a completely effective transferral of scene detail to the electrical signal. This failure to provide distinct vertical resolution lines is illustrated in Figure 17.

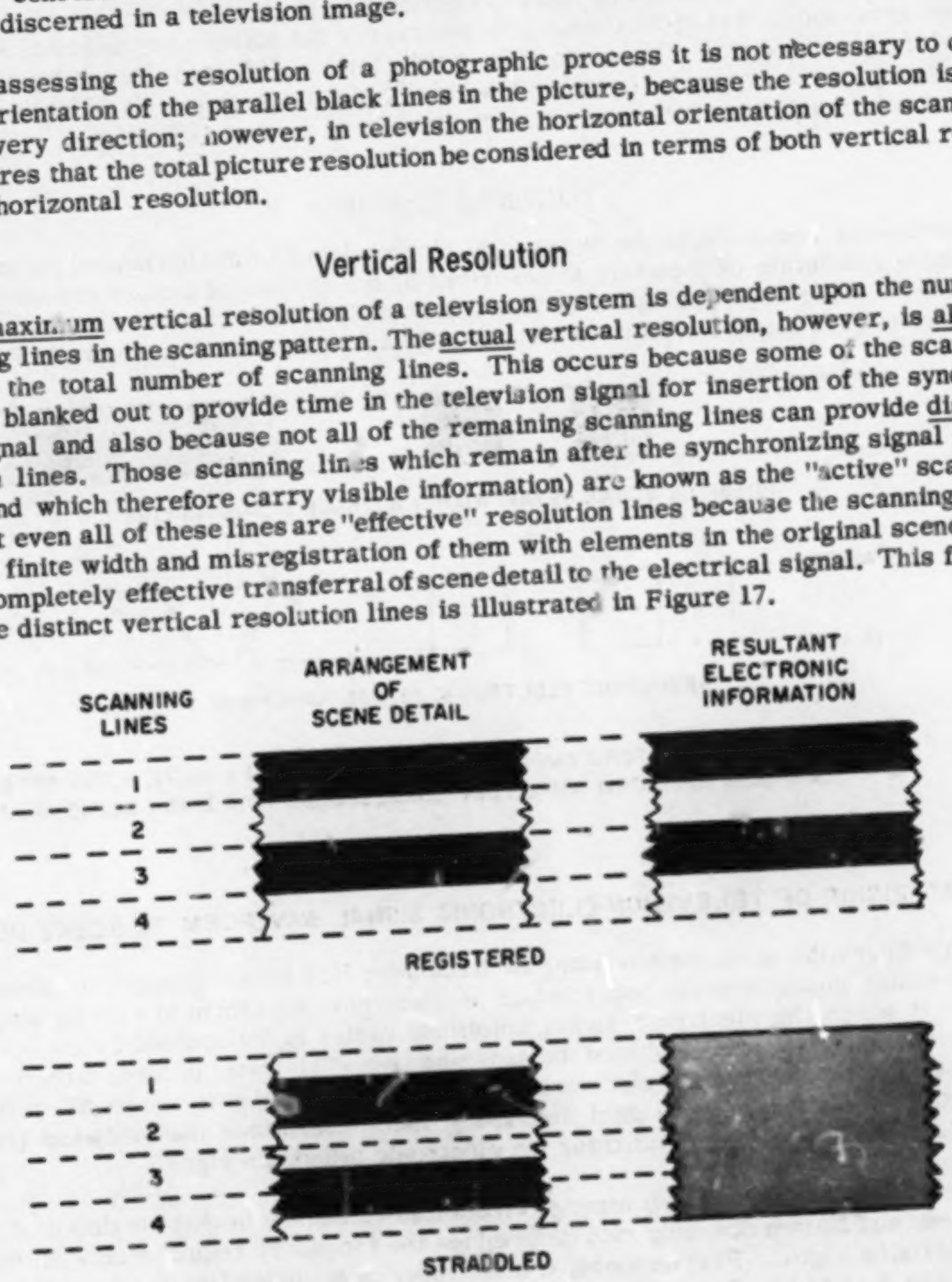


FIGURE 17

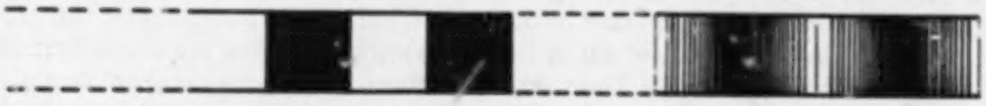
EFFECT OF SCANNING LINE REGISTRATION ON VERTICAL DETAIL

In this figure it can be seen that in the event of perfect registration between scanning lines and scene detail all of the scene detail would be transferred to the electronic signal. In a case of complete misregistration, i.e., a case in which the scanning lines exactly straddle the detail of a television scene, no distinct detail would be transferred to the electronic signal.

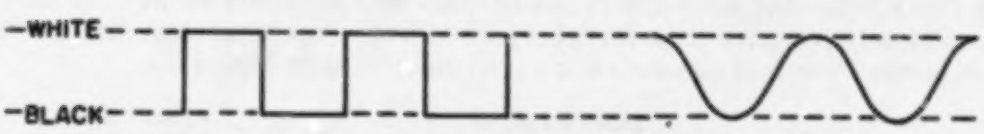
These are the extremes of registration possibilities between television scanning lines and television scene detail. Actually, picture details generally have a somewhat random spacing with respect to scanning lines. Experience with, and tests on* the U.S. broadcast system have shown that approximately 70 per cent of the active scan lines are effective in reproducing scene detail. This means that out of a total of 525 scan lines in the U.S. broadcast system, there are approximately 495 active lines and approximately 350 effective lines. The vertical resolution of this system when optimized, is, thus, 350 lines.

Horizontal Resolution

Horizontal resolution is the measure of picture detail in the horizontal direction. The horizontal resolution of a picture is described by the number of picture elements that can be resolved along the scanning lines. The relationship of television scene detail to the resultant television signal waveform with negligible aperture distortion shown in Figure 18.



POSSIBLE SCENE DETAIL WITHIN A SINGLE SCANNING LINE



RESULTANT ELECTRONIC SIGNAL WAVEFORM

NOTE: MAXIMUM WAVEFORM AMPLITUDE CORRESPONDS TO A WHITE SCENE AREA
MINIMUM WAVEFORM AMPLITUDE CORRESPONDS TO A BLACK SCENE AREA

FIGURE 18
RELATIONSHIP OF TELEVISION ELECTRONIC SIGNAL WAVEFORM TO SCENE DETAIL

In this figure the scene details along each scanning line create changes in the intensity of the scanning electron beam and produce an electronic waveform of varying amplitude. The rate at which the electronic signal amplitude varies is determined by the number of picture elements along the length of the scanning line. This rate, in turn, directly determines what the frequency of the electronic signal must be in order to accurately follow the scene detail. The maximum signal frequency then determines the bandwidth (range of frequencies) which must be provided for the electronic television signal.

The very important fact that emerges from this reasoning is that the detail of a television scene and chosen scanning rate determines the frequency requirements of the electronic television signal. Furthermore, if the number of scanning lines and the frame rate are fixed, as they are in the U.S. broadcast system, it is the horizontal picture detail that determines the signal frequency necessary for accurate electronic reproduction of scene detail. A corollary of the foregoing theorem states that the available bandwidth determines the rate at which the electronic signal may vary and thus produce a given scene detail. The corollary is equally as important as the theorem, but it is more restrictive in its scope. It applies directly to the U.S. broadcast system and any other system where a limited frequency bandwidth is fixed by Federal Rules and Regulations.

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*Fink, op. cit., p. 28.

The vertical resolution of the U.S. broadcast system is approximately 350 lines. Since square detail elements are the most convenient and logical to deal with, the horizontal resolution should also be 350 lines. But the television picture is not square; its ratio of width to height (aspect ratio) is 4 to 3. There should, therefore, be 4/3 x 350 = 467 detail elements in the horizontal direction. The shortage of radio frequency space in the U.S. has, however, caused a specific bandwidth limitation to be established for television, and this restricts the maximum achievable horizontal resolution for the broadcast standards to approximately 450 elements or horizontal lines.

Figure of Merit

The total number of picture elements that may be resolved in a picture area describes the resolving ability of the visual process. This number may be described as the figure of merit.* In television, this figure is the product of the horizontal resolution, the vertical resolution, and the aspect ratio. In the U.S. broadcast system this is approximately 350 x 450 = 157,000 elements. In comparison there are approximately 250,000 effective picture elements in a single frame of 16 mm film. In both instances, reference is made to maximum resolution of the systems.

Contrast

In addition to reproducing black and white picture elements, a television system must also be capable of reproducing the full range of contrast between black and white. The ability of a television system to do this is measured in the number of shades of grey that can be reproduced. This ability is dependent upon the range of scene light levels that the camera tube can transfer to an electronic signal (camera dynamic linearity), upon the range of contrast that can be reproduced on a receiver screen, and the dynamic linearity of the total transmission system. It is significant to note that the television process can accurately reproduce a contrast range of only about 30 to 1 (in an optimized system) whereas the human eye can perceive a contrast range of approximately 100 to 1.

USING A TEST PATTERN TO MEASURE QUALITY

The quality of a television picture depends on synchronization, linearity, noise, and bandwidth. Since so many factors are involved it is often difficult to determine the exact cause of picture impairment by simple examination of a normal picture. But television is a visual process and the ultimate judgment of its fidelity must be dependent upon a viewing of a picture. For this reason it is common practice to employ a test pattern which is designed to facilitate the identification of specific problems. Although it is by no means the only testing method, the use of a test pattern is very useful in evaluating and adjusting all the components of a television system, including the cameras, transmission systems, and display devices.

Test patterns are valuable in evaluating television video system performance because a distant viewer can measure the quality of the picture he is viewing and can readily detect degradations. They are also valuable because the viewer can compare actual performance with possible performance.

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*D. G. Fink, op. cit., pp. 26 and 30.

The test pattern illustrated in Figure 19 is a reproduction of the pattern developed by the Electronic Industries Association (EIA). It is often used by their members as a source of material for the testing of manufactured equipment and by broadcasting studios as a signal quality standard to maintain optimum equipment performance.

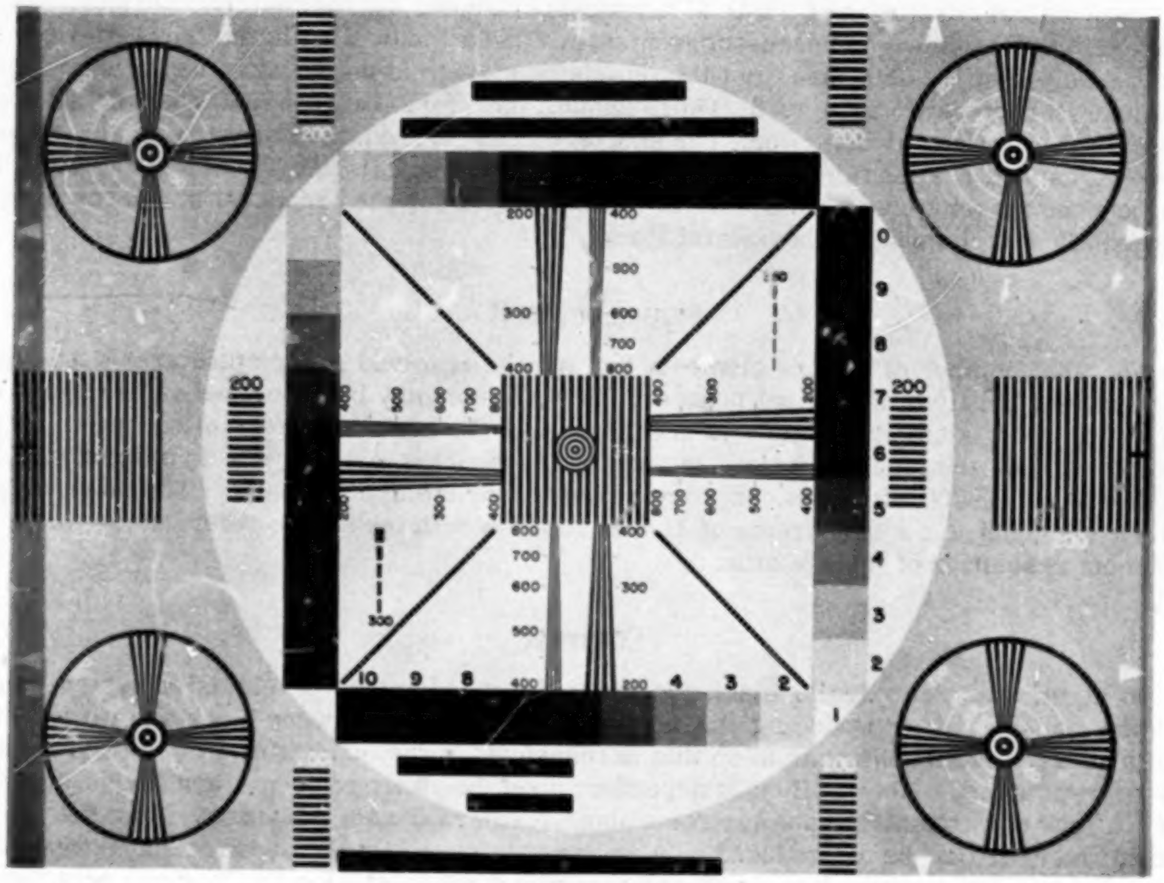

FIGURE 19
EIA TEST PATTERN

The following is a description of the pattern's use in checking the quality of the picture and interpreting the results.

Horizontal Linearity

This may be determined by checking the large circle, the four corner circles, and the three squares of "200 line" vertical bars, one on each side of the picture and one in the center. The circles should show no distortion and the horizontal length of all squares should be equal.

Vertical Sweep Linearity

The circles plus the six sets of short "200 line" horizontal bars may be used to check linearity of the vertical sweep. The circles should show no distortion and the overall height of the sets of bars should be equal.

Contrast

The four bars at the ends of the central wedges are the grey scales. Each is composed of 10 steps varying from maximum white brightness to approximately 1/30th of this value. If the received signal has the proper distribution of greys, it will be possible to distinguish all squares in the scales. Loss of distinction between the individual squares is an indication that the gain of the overall system is not constant over the full range of the input video signals.

Aspect Ratio

The four grey scale bars should form a perfect square.

Interlace

The quality of interlace may be checked by noting the condition of the four diagonal lines in the center. A serrated or jagged line indicates pairing of the interlace lines, and hence poor interlace.

Streaking

Streaking following any one of the two horizontal balck bars, at top and bottom of the large circle, indicates low-frequency phase and/or amplitude distortion. The bars represent half cycles of square wave signals ranging from about 30 kc for the longest to 100 kc for the shortest. They help to locate the frequency range where the phase distortion takes place. For instance, if it is near 100 kc, the short bar will have more intense streaks than the others.

Ringing

The vertical wedges and the short vertical lines or ringing bars, between 100 and 300 in the lower left quadrant of the circle, along with those between 350 and 500 in the upper right quadrant, are used to check ringing, a kind of spurious electrical vibration. The frequency of the ring will be indicated on the vertical wedges by the vertical position at which the strongest ring is indicated to the right or left of the wedge. Similarly, the short vertical line that gives the strongest ring will indicate the ringing frequency.

Resolution

Vertical resolution, the resolution from top to bottom of the picture, is expressed as the number of horizontal lines that can be resolved. Therefore, the horizontal wedges in the test pattern are used to measure vertical resolution.

Horizontal resolution is based upon the number of distinct black and white dots (vertical lines) that can be reproduced by the picture monitor in three-quarters of the usable (visible) length of a horizontal scanning line. This length of three-quarter width is selected because it equals the height of the picture, and therefore gives a basis for direct comparison between horizontal and vertical resolutions. The vertical wedges are used to determine horizontal resolutions.

Vertical or horizontal resolution can be measured in terms of lines by determining the point on the horizontal or vertical wedges to which it is possible to distinguish distinct lines. The wedges in the center and the four corners are calibrated in lines. The central wedges vary from 200 to 800 lines, while those in the corners vary between 200 and 600 lines. The vertical and horizontal linearity bars are all spaced for 200 line resolution. The concentric circles in the centers of the corner circles are at 150 line spacing. Those at the center of the large circle are at 300 line spacing.

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APPENDIX B

Design Factors in a Microwave Relay System

The quality of a television transmission system may be measured in terms of the effect which the transmission system has upon the signal-to-noise ratio, and picture and sound impairment.

SIGNAL TO NOISE RATIO

The tolerable signal-to-noise ratio at the output of a receiver depends largely upon the type of signal observed and the judgment of the viewer. For a television signal, it becomes a matter of how much noise becomes objectionable to the viewer or affects his ability to discern the subject matter presented. The results of tests based on a 525 line, 4.0 Mc broadcast television system are tabulated below. In acordance with television practice, S/N is expressed as a ratio of peak-to-peak (P-P) signal voltage to root-mean-square (RMS) noise voltage.

Quality	S/N (P-P VIDEO) (RMS NOISE)
No perceptible noise....................	Above 42
Tolerable noise....................	26 to 42
Intolerable noise....................	Below 26

These figures are approximate and based on subjective judgment of picture quality, but are generally accepted by the television industry. They apply to the measurement of the random noise in a 4 Mc unweighted video bandwidth.

The subjective tolerance to high frequency noise is much greater than to low frequency noise because the high frequency noise produces only small disturbances, known as "snow," in the television picture, whereas the low frequency noise produces lines across the screen which are present for longer periods of time. A filter which de-emphasizes the subjective value of high frequency noise is generally used in making noise measurements. Weighting curves which take account of the filter characteristics are normally used for specifying the effective (weighted) signal-to-noise ratio on a subjective basis. The effect of the filters and the curves is to reduce the effects of high frequency noise. High frequency noise, though not highly disturbing to the viewer, does have the effect of lowering the effective resolution.

When noise weighting is used in 525 line, 4 Mc television, the requirement is for a signal-to-weighted-noise ratio that is 6 to 8 db higher than the signal-to-unweighted-noise ratio. CCIR (International Radio Consultative Committee) recommendations specify a 56 db weighted S/N for high quality television relay over long distances. For 4 Mc television, this is a 6 db increase over a 56 db S/N unweighted figure, which is sufficiently above the minimum 42 db figure to be completely noise free (or rather snow free) to an experienced observer viewing on a high resolution monitor.

LINEARITY

The frequency and phase linearity of a transmitter, receiver, or repeater used in a microwave system is a measure of its ability to handle signals without distortion, or in other words, to preserve the fidelity of the original signal. The over-all frequency and phase linearity of a microwave system operating on one, several, or many hops is dependent on the frequency and phase linearity of the system components and upon the alignment (or tuning) of the transmitters and receivers throughout the system. In other words, if the receiver is not properly "tuned" to the frequency it is intended to receive, amplitude and phase distortion may result.

NETWORK TRANSMISSION LINEARITY

Distortion may result because of the non-linear dynamic — or amplitude — characteristics of the components in a microwave system. Such distortion may result from the components involved in demodulation and remodulation in a so-called "back-to-back" microwave repeater. Such a repeater demodulates a received signal and uses it to modulate a new carrier for re-transmission. Literally, it is a complete receiver and complete transmitter connected "back-to-back."

Demodulating and remodulating signals inevitably adds to the distortion, as does any stage of signal processing. The effect is, quite naturally, cumulative with the number of repeaters the signal passes through. It is for this reason that "I.F. heterodyne" repeaters are beginning to be used on long haul systems. This type of repeater translates or "heterodynes" the received signal at the intermediate frequency (IF). Because of the difficulty of obtaining power amplification at microwave frequencies without degrading signal quality, and the convenience with which switching may be accomplished between systems, amplification of the I.F. has proven much more practical. The amplified I.F., signal is then translated back up to a new carrier frequency and re-transmitted. This procedure completely eliminates the demodulation and remodulation steps, and thus significantly improves individual repeater linearity. The major distinction between the heterodyne and back-to-back repeater is that the former does not reduce the received signal back to the original video and audio baseband, whereas the back-to-back repeater does.

The future should see more I.F. heterodyne repeaters used on contemplated long haul systems, with back-to-back equipment limited to systems of three hops or less, or to short "spurs" branching off from long haul systems.

The problem of maintaining linearity is one that must be carefully considered in the design of all system elements, and becomes increasingly complicated as the amount of equipment in a multi-hop system increases.

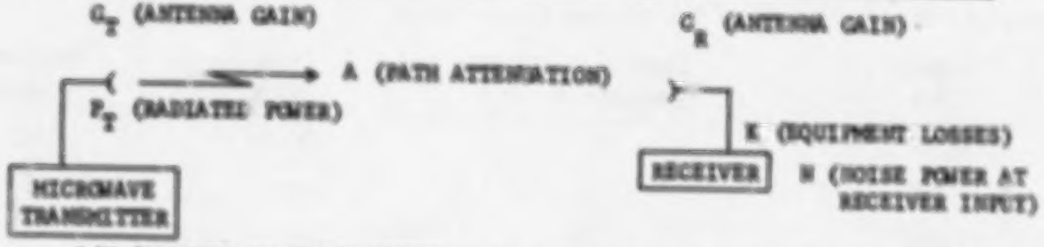
BASIC PARAMETERS OF A MICROWAVE LINK

The basic parameters which must be considered in engineering a microwave link are radiated power, antenna gain, path attenuation, equipment losses and receiver noise. These parameters are included in Figure 20 which includes a computation using typical values; it is highly idealized in that the inevitable vagaries of propagation in the atmosphere are not taken into account. The propagation medium — in this case the atmosphere — is very much a part of the over-all system, and its characteristics have a very profound effect on the ultimate system design. These are discussed in later sections entitled "Allowances for Atmospheric Fading," "Choice of a Frequency Band," and "Path Clearances."

1. Radiated Power

The amount of transmitter power than can be achieved in practical tube design usually decreases as the frequency increases. The current commercially available microwave transmitter tube powers are listed below. It will be observed that as the frequency increases, the maximum available tube power decreases:

Frequency Range (Mc)	Typical Transmitter Power
1700 - 2300	10, to 15 watts
5900 - 7425	0.1, to 1.5 watts
10,700 - 13,250	0.1, to 0.1 watts



C/N (CARRIER TO NOISE RATIO) $= P_T + G_T + G_R - A - K - N$

WHERE $N = -114 + 10 \log B + NF$

TYPICAL VALUES (30 MILE HOP AT 6000 MC)

P_T = 1 WATT = 30 DBM

G_T = 43 DB

G_R = 43 DB

A = 138 DB

K = 7 DB

NF = 12 DB

B = 4 MC

N = -96 DBM

AND THEREFORE C/N = 67 DB

FIGURE 20

MICROWAVE LINK COMPUTATION

2. Antennas

Parabolic reflectors or "dishes" are generally used at microwave frequencies to concentrate the signal energy into narrow beams, thereby effectively increasing the transmitter power in the direction of the receiver. Parabolas are also used for receiving. The gain of such a parabola is proportional to the square of its diameter. Taking many factors into consideration, an efficiency of 55 per cent is readily realizable in practice and results in an antenna gain which may be calculated from the following expression:

$$G + 20 \log F + 20 \log D - 52.5$$

Where

G = gain in db above an isotropic antenna

F = frequency in megacycles

D = diameter of parabola in feet

The beamwidth of a signal transmitted from parabolic antenna is inversely proportional to the diameter and the frequency. For practical antennas having a 55 per cent efficiency, the beamwidth may be approximated by:

$$\text{Beamwidth in degrees} = \frac{6.4 \times 10^4}{F \times D}$$

where F and D are defined as above.

Theoretically, any desired gain may be obtained by increasing the antenna diameter, but the reduced beamwidth limits the maximum size of the parabolic dish to approximately 10 feet at 7,000 Mc. For higher microwave frequencies, the size is generally limited to something less than this to prevent the beamwidth from being so small as to require extremely rigid supporting structures so that no loss of received signal will be experienced due to swaying of the tower structure under the influence of strong winds.

The fact that some beam misalignment can occur is a significant factor in microwave system design. This phenomenon varies with atmospheric conditions and imposes a maximum limit on antenna size to correspond to a beamwidth of about 1 degree. Thus, parabolic antenna size at 2,000 Mc and 6,000 Mc is limited to a maximum size of about 10 feet. These limitations are tabulated below along with the resulting antenna gains that can be achieved in practice for three sets of microwave frequencies:

Frequency (Mc)	Typical Antenna Diameters (Ft.)	Gain (db)	Beamwidth (deg.)
2,000	10	33.5	3.2
6,000	10	43	1.2
12,000	5	43	1.2

3. Path Attenuation

The path attenuation, or loss in signal power level between transmitting and receiving antennas, is usually computed for ideal or "free space" conditions. The effects of such things as atmospheric fading can then be separately assessed and treated by providing a margin of safety known as fade margin, which must be included in the system design. Under such conditions the path attenuation in decibels is proportional to the log of the frequency and to the log of the distance between transmitter and receiver. When frequency (F) is expressed in megacycles and distance (D) is expressed in miles, the path attenuation in decibels is:

$$A = 36.6 + 20 \log F + 20 \log D$$

Using this relation on a 30 mile path reveals that the free space attenuation varies from approximately 132 db at 2,000 megacycles to 149 db at 14,000 megacycles.

4. Fixed Equipment Losses

The principal loss of signal in the equipment occurs in the transmission of signal from transmitter to antenna and from antenna to receiver. While there is a significant increase in transmission line attenuation with frequency, there are certain practical techniques that offset this fact so that it is reasonable to assume the same over-all transmission loss in equipment operating in any of the bands under consideration. These techniques involve the use of passive reflector systems at 6,000 Mc and 12,000 Mc instead of the use of coaxial lines typical of 2,000 Mc systems. In passive-reflector systems the antenna is located at the base of a tower and a reflector is located at the tower height which will provide the required path clearance. While not practical at 2,000 Mc, this system eliminates the need for transmission line on the tower at 6,000 Mc and 12,000 Mc.

5. Receiver Noise

An ideal receiver would contribute no noise to a received signal. Nevertheless, an ideal receiver would still amplify that noise present at the antenna terminal falling within the receiver passband, and this noise would appear with the signal at the receiver output. At microwave frequencies, barring signals from interfering transmitters solar and cosmic noise sources, the noise present at the receiver antenna terminal is primarily "thermal" or "random" noise, which by nature, covers the entire spectrum with a nearly constant power density over the spectrum. This type of noise is equivalent to that generated by the thermal motion of electrons in a resistor. In fact, a resistor matched to the receiver antenna terminal impedance and maintained at a temperature of 290° Kelvin (17° Centigrade, or approximately room temperature) is taken as a nominal value for calculating receiver noise level characteristics. Thus, the noise power in watts present at the antenna terminal of a receiver under this condition is:

$$P = KTB$$

where:

K = Boltzmann's constant — 1.38×10^{-23} joules/K°

T = Temperature in degrees Kelvin

B = Receiver noise bandwidth in Mc

For T = 290° K, this is computed to -114 dbm (about 0.000000000000004 watt) per megacycle of bandwidth. The output noise level of an ideal receiver under these conditions would simply be the result of the receiver gain and detection characteristics. Unfortunately, however, the output noise level of a typical microwave receiver having identical gain and detection characteristics would be greater, because it contributes noise generated in the first amplifier stage. In other words, a typical receiver can be treated as though it were an ideal receiver with an equivalent noise input greater than the noise power of -114 dbm per Mc available from the antenna. The ratio of this equivalent noise power input in watts to the KTB value is the receiver "noise factor," a factor often used as a measure of merit or quality of a receiver. The difference between the two power levels experienced in db is referred to as the "noise figure" of the receiver. Some typical noise figures for microwave receivers, and the resulting equivalent noise powers referred to the antenna inputs (-114 dbm/Mc less noise figure in db), are given below:

Frequency (Mc)	Noise Figure (db)	Noise Level Referred to Input (dbm/Mc)
2,000	10	-104
6,000	12	-102
12,000	14	-100

Note that the noise power level increases with bandwidth. The complete expression for noise power in dbm is:

$$N = -114 + 10 \log B + NF$$

where

N = equivalent noise power at receiver input in dbm

NF = noise figure in db

B = noise bandwidth in Mc

ALLOWANCES FOR ATMOSPHERIC FADING

1. Fading and System Reliability

Although calculations of received signal level in a microwave link may be based on free space conditions, variations in the signal caused by atmospheric variations and by heavy precipitation, affect the free space conditions drastically. It has been found that a variation in signal level due to reflection and/or refraction within the atmosphere and from the terrain over which the signal passes will cause a fluctuation of signal which is primarily a function of hop length and terrain clearance. The degree of fading experienced on a particular hop differs in different parts of the country, because it is dependent on the particular terrain and wind conditions. This type of fluctuation is significantly serious and must be compensated for in system design.

Figure 21 shows the fading margin or margin of received signal as a function of distance and reliability necessary to account for possible fading. Reliability is a statistical measure and indicates the percentage of time that the signal will be above a minimum acceptable level.

Table IX shows the amount of outage time over yearly, monthly and daily periods for various propagation reliabilities. It is important to realize that the actual fading (and hence required fade margin) varies considerably and that the reliability figures shown here are based on periods of time of at least one year. Short term fading will be most severe between 12 a.m. and 6 a.m. in late summer, due to variations in atmospheric inhomogeneities.

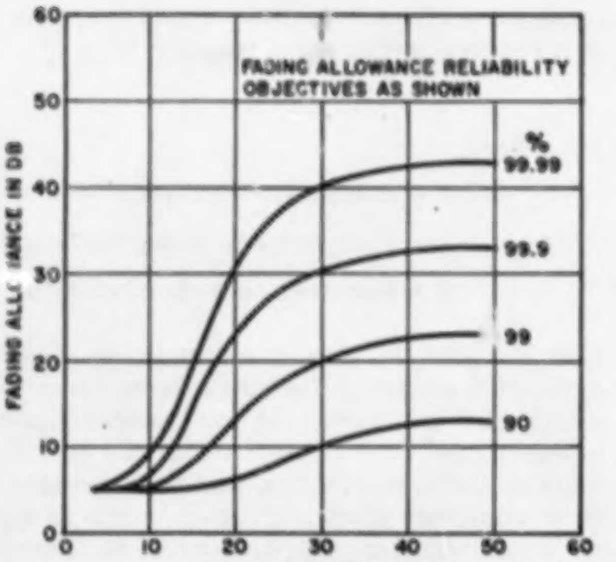


FIGURE 21

FADING RELIABILITY VS PATH LENGTH

Atmospheric fading is a statistical phenomenon. Fades will not occur in the same pattern over different paths; therefore, the effect is not readily predictable for a specific plane and time. It may be assumed that deep fades will not occur over several hops simultaneously. Rather, the fades on several hops will follow a statistical variation that effectively increases the number of fades, but does not directly increase the depth of the fades. The accumulated field data shows that while hop length is the most significant factor affecting fading, fades appear to be more rapid and have greater depth at higher frequencies while fades are less deep but of larger duration at the lower frequencies. Therefore, the total accumulated outage time over a greater period is essentially the same for all microwave frequencies.

TABLE IX

FADING ALLOWANCES

Reliability Per Cent	Outage Time Per Cent	Outage Time Per: Year	Outage Time Per: Month (Avg.)	Outage Time Per: Day (Avg.)
90	10	876 hrs	72 hrs	2.4 hrs
99	1	88 hrs	7 hrs	14.0 min
99.9	0.1	8.8 hrs	43 min	1.4 min
99.99	0.01	53 hrs	4.3 min	8.6 sec

2. Application of Fade Margins

The fading allowance (or fade margin) determined from Figure 21 for a desired propagation reliability, must be added to the minimum acceptable carrier-to-noise ratio to determine the unfaded carrier-to-noise ratio (C/N) for which the microwave link should be designed. The unfaded C/N is that given by the equation of Figure 20. Either one of two things may limit the minimum acceptable C/N. One is, of course, the receiver threshold level, below which C/N cannot fall without virtually a complete loss of signal.

CHOICE OF FREQUENCY BAND

Obviously the most critical needs for optimization of system parameters exist in the case of long haul relay stations where it is important to keep the number of stations at a minimum. Therefore, the problem is to achieve maximum hop length while satisfying the requirements of system performance.

The basic parameters of a microwave link have been discussed in the preceding paragraphs. The equation relating these parameters, shown in Figure 20, is restated below:

$$C/N = P + G_t + G_r - A - K - N$$

where

C/N = Fade-free carrier-to-noise ratio.

P = transmitter power in dbm or dbu

G_t and G_r are the transmitting and receiving antenna gains in db

A = free space attenuation in db

K = fixed losses in db

N is the receiver noise power in dbm or dbu

These parameters, except N, are independent of bandwidth. Values typical of current commercially available equipment are used to derive the chart below. A transmitter power of one watt and bandwidth of 10 Mc are assumed for comparative purposes:

Frequency (Mc)	$G_t + G_r$ (db)	A (db)	K (db)	N (dbm)	C/N at 30 mi. (db)
2,000	67	132.5	7	-94	51.5
6,000	86	142.1	7	-92	58.9
12,000	86	148.1	7	-90	50.9

The above tabulation shows that in the absence of atmospheric fading and on the basis of antenna limitations already discussed, the best C/N is obtained with a carrier frequency of 6 kMc. As for the 2,000 and 12,000 Mc bands, taking various factors into consideration, one appears as good as the other; however, each frequency band exhibits a unique set of advantages and disadvantages which the designer must take into consideration for any given application.

Attenuation due to rain and other forms of precipitation along a path increases significantly as frequency increases. Experimental results on some paths have given quantitative information which may be related by the empirical formula:

$$\text{Rain attenuation (db/mile)} = \frac{Qf^2}{3 \times 10^3}$$

where

Q = rate of rainfall in inches/hour

f = frequency in megacycles

Specifically, the effects of rain increases as the square of the frequency and become quite large above about 14 kMc. Figure 22 is a graph of the formula above for moderate and heavy rainfall. For heavy rain extending over a 30 mile path, the attenuation varies from 1.3 db at 2 kMc to 66 db at 14 kMc. Heavy rains of this intensity are unusual over a large area of the country and occur only rarely. Moderate rains occur more frequently and are more widespread; consequently, for this type of rain, the attenuation varies from 0.27 db at 2 kMc to 13 db at 14 kMc over a 30 mile path. Although the attenuation caused by the atmosphere and terrain is statistical and generally will not occur simultaneously on several paths, rain attenuation can. Also, whereas atmospheric and terrain attenuation is only an average value of seconds or minutes considered over the long period of time, the

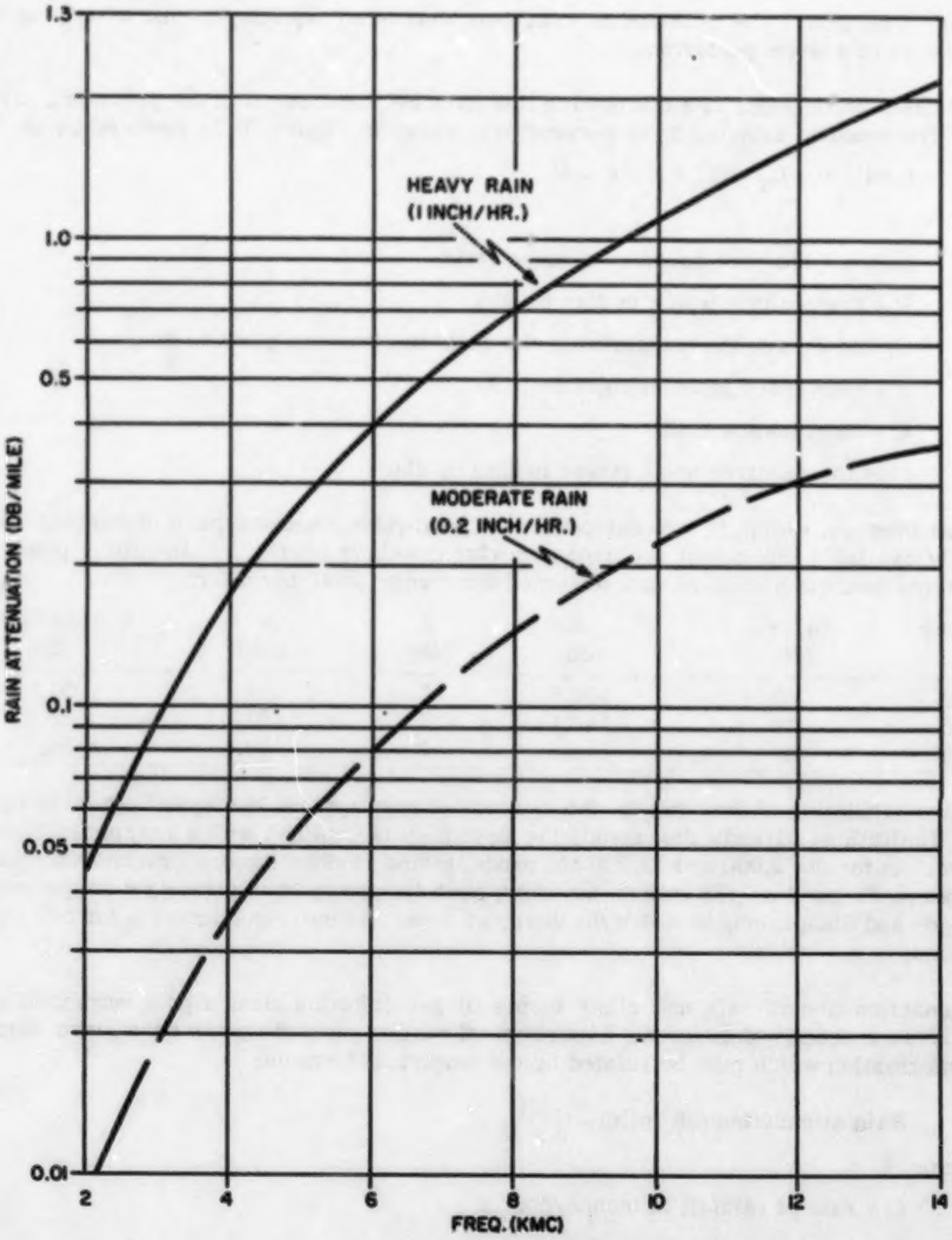


FIGURE 22
ATTENUATION DUE TO RAIN

rain attenuation is present for the length of the rainfall, and consequently, a transmission path may be "washed out" for several hours or even a day. Therefore, it is necessary to compensate for rain attenuation at higher frequencies by the use of higher power, or shorter paths, or both.

The effects of multipath fading and rain attenuation will not generally occur simultaneously, since precipitation is generally accompanied by air motion which "breaks up" atmospheric effects leading to multi-path fading. The fact that the rain attenuation may be present for an extended period of time can greatly influence the choice of operating frequency.

PATH CLEARANCE

Microwave signals exhibit transmission properties similar to those of light waves; consequently the path between the receiver and transmitter must be well clear of obstacles. This includes the curvature of the earth. To permit efficient propagation, it is necessary to provide a certain minimum clearance above obstructions to achieve more than mere line-of-sight clearance between transmitter and receiver. This minimum clearance is referred to as the "first Fresnel zone" clearance and permits a volume of wave front containing the principal energy used for transmission to pass unobstructed and without harmful reflection of energy from the ground or water surfaces.

The choice of microwave sites to achieve Fresnel zone clearance and minimize harmful surface reflection is one of the most important factors in microwave path engineering. The required Fresnel zone clearance decreases with frequency; consequently it is necessary to provide higher antenna towers at lower frequencies for the same path length. For a 25 mile path, the tower heights required to provide Fresnel zone clearance at mid-path vary from approximately 300 feet at 2,000 megacycles to 175 feet at 14,000 megacycles. Therefore, the lower frequencies will require the use of longer transmission lines or waveguides to reach the antennas. In most parts of the country, advantage is taken of natural terrain height to reduce the height of the supporting towers.

RELATIONSHIP BETWEEN SINGLE HOP AND MULTIPLE HOP PROPAGATION EFFECTS

Most of the discussion thus far on microwave interconnection has centered around "single hop" transmission. In practice, of course, if the distance to be covered exceeds 30 miles or so, the signal must be received, amplified and retransmitted by "relay" or "repeater" stations located between the point of origin and the terminal receiver. Each transmission-reception path is referred to as a "hop" and as has been previously indicated, it may well require 100 hops or more to transmit a television signal over transcontinental distances. Questions which may well arise at this point are:

1. How is the number of hops and length of individual hops determined?
2. What happens to the all-important signal-to-noise ratio in multihop system?
3. What happens to the reliability as determined from the fading allowance for a multihop system?

Answers to these questions are discussed in the paragraphs which follow.

1. Number of Hops and Hop Length

For economic reasons, it is desirable to use a minimum number of relay stations between two points to be interconnected. This means, of course, making the length of single hops as long as practical. This length, however, is limited by the need to maintain a certain unfaded carrier-to-noise ratio at the receiver input, and to minimize the probability of fading. Using currently available transmitter powers, practical antenna sizes, typical bandwidth allocations and other current equipment limitations, a path length of about 30 miles has been found to be about maximum. Improvements in equipment, such as greater transmitter power or lower receiver noise figures, could increase this figure in the future. However, limitations imposed by terrain cannot be overlooked. The location of available land, the location of hilltops or mountain peaks suitable for antenna siting, and the ability to obtain path clearance between two points usually exert a governing influence on maximum path length.

2. Effect on Signal-to-Noise Ratio

In multihop transmissions, the noise of each repeater adds to the total noise that appears with the signal at the terminal receiver. This may, at first, appear difficult to reconcile with the fact that an FM Noise Improvement is obtained at each repeater. However, it should be understood that the noise suppression properties of an FM receiver apply only to the "incoherent" noise present at the receiver input. Noise picked up at preceding points in the network becomes an indistinguishable part of the signal which is to be used by the succeeding receiver.

The signal-to-noise ratio of this combined "signal," which is really the desired signal plus accumulated noise, can never be improved upon. The improvement factor of a receiver is simply a measure of its ability to discriminate against the additional incoherent noise introduced at the receiver. The amount of noise added by a repeater can be expressed as a fraction of the signal at the output of the repeater. This fraction is simply the reciprocal of the familiar signal-to-noise ratio, and is designated N/S. For example, if the signal-to-noise ratio at the output of the first repeater in a network is 50 db, or in other words, 100,000 to one, the fraction of noise added by the first repeater is 0.00001, or 10^{-5}. If the second repeater also has a 50 db signal-to-noise ratio, it adds another fraction of 0.00001, so that the total fraction of noise is now 0.00002.

To be precise, the "signal" at the input of the second repeater actually consists of both the original signal plus the noise of the first repeater; thus the noise contribution of the second repeater should actually be multiplied by 1.00001 in order to reference it to the original signal. However, the error resulting from simply adding the reciprocal signal-to-noise ratios associated with each hop is slight, so long as the noise level is small by comparison with the signal level, a mandatory condition for good television reception. An approximation for the signal-to-noise ratio at the output of a multihop chain is:

$$S/N = 1 \Big/ \left(\frac{N_1}{S_1} + \frac{N_2}{S_2} + \frac{N_3}{S_3} + \cdots + \frac{N_n}{S_n} \right)$$

$\frac{N_1}{S_1}$ = reciprocal of the signal-to-noise ratio associated with the first hop.

$\frac{N_2 \; N_3}{S_2 \; S_3}$ etc. = reciprocal of the signal-to-noise ratio associated with the second hop, third hop, through the nth hop, as indicated by the subscripts.

n = number of hops.

If for simplification, all hops are assumed to have the same, or nearly the same, signal-to-noise ratios, this equation simplified to:

$$S/N = 1 \Big/ n \left(\frac{N_1}{S_1} \right) \quad = \frac{1}{n} \; \frac{S_1}{N_1}$$

expressed in logarithmic form:

$$(S/N)_{db} = (S_1/N_1)db - 10\log n$$

where signal-to-noise is now expressed in decibels. These equations indicate that two identical hops will reduce the signal-to-noise ratio 3 db below that of hop only. Ten identical hops will reduce the signal-to-noise ratio 10 db below that of the first hop, and 100 identical hops will reduce the signal-to-noise ratio 20 db below that of the first hop. In multihop systems, allowances must be made for the resulting decrease in signal-to-noise ratio.

Although it has been shown that the signal-to-noise ratio decreases with the number of hops, it does not follow that the fewer the number of hops used to cover a fixed distance, the better the signal-to-noise ratio at the terminal receiver. Given a specified distance to be covered by a multihop microwave link, the signal-to-noise ratio at the terminal receiver may actually improve by increasing the number of hops. This is possible because the individual hop path length must decrease as the number of hops increases. Thus, the signal-to-noise increase obtained by shorter paths may well exceed the decrease, resulting from the use of a greater number of repeaters. These are the kinds of system alternatives the designer must thoroughly investigate before completing the design. Nevertheless, the cost of repeater stations still dictates that hop path lengths should be made as long as feasible, still meeting limitations set by transmitter power, bandwidth, fading allowances, desired signal-to-noise ratio, and terrain.

3. Propagation Reliability and Fading Allowance

Fades do not generally occur simultaneously on any two hops of a multihop system. If a fading allowance has been made for a particular hop above what is considered to be a minimum acceptable signal-to-noise ratio, than a fade greater than this allowance effectively renders this hop, and the whole system in which it is a link, inoperative. The reliability figure associated with the allowance is the percentage of time that the link can be expected not to be made inoperative because of fading. Obviously, the reliability percentage for a number of hops in series is less than for a single hop, since each hop represents another opportunity — or probability — for fading to occur.

Strictly speaking, the possible propagation reliability of a number of hops is the product of the reliability, expressed in decimal form, of all the individual hops. For example, in a ten hop chain each hop having a reliability of 99.9 per cent, the over-all reliability of the chain would be 0.999 multiplied by itself ten times, or $(0.999)^{10} = 0.99007$ or 99.007 per cent.

There is, however, a simpler approach which provides accurate answers as long as the reliability figures are close to 100 per cent, as they must be in practical microwave systems. In the simpler approach, the expected "outage" time for each hop is added to the expected outage times for all the other hops to obtain the total outage time for the chain. If the reliability figure for a single hop is 99.9 per cent, the expected "outage" is 0.1 per cent of the time. In the example just given, the outage for the whole system would be $10 \times 0.1\% = 1.0\%$. The percentage reliability for the complete ten hop chain is then 100 per cent − 1.0 per cent = 99.0 per cent.

Alternately, if a certain reliability is desired for a chain of stations, the reliability required for the individual hops can be determined by dividing the total tolerable outage by the number of hops. If it is supposed the desired reliability for the ten hop chain just discussed is 99.9 per cent, the tolerable outage is only 0.1 per cent. This divided by ten is 0.01 per cent, the tolerable outage for each hop. The percentage reliability required per hop is therefore $100\% - 0.01\% = 99.9\%$. However, it should be noted that the above method for computing multihop system reliability produces a figure lower than that which may be experienced in practice, since as a first-order approximation, the total system outage may be taken as the "root-sum-squared" value rather than the linear value.

The effect of rain over any number of hops decreases the obtainable signal-to-noise at the end of a series of hops more seriously than statistical fading. Its effects are drastic in that they exist for longer periods of time, and are cumulative. Although the actual attenuation differs according to where in the system it occurs, on a nationwide network it is not unreasonable to assume that rain may be present on many separate paths. Heavy rain can "wipe out" the entire network if it causes the carrier to drop below the critical level. Consequently in multihop systems, frequencies above 8 or 10 kMc may be unsatisfactory unless additional carrier fade margins are used in areas where heavy rain can be expected. Frequencies of 12 kMc and above are even more hazardous, since the attenuation due to rain increases as the square of the frequency.

In order to determine the effect of fading or rain attenuation which is less than the critical value which will render a system inoperative, references must be made to the discussion as the effects of multihop networks on signal-to-noise ratio. The effect of fading over a particular hop is to increase the amount of noise added to the signal over that hop. This noise adds to the noise contributed by other hops as described above.

On very long haul systems, or systems on which reliability is extremely important, "space" and/or "frequency diversity" techniques are sometimes employed. In space diversity, two and sometimes more receiving antennas are used to receive the same signal. They are purposely spaced several hundred wavelengths apart, but usually located on the same antenna tower. With sufficient spacing, the fading experienced by one antenna is independent of the fading experienced by the other. This is another way of saying that the two signals are statistically uncorrelated. The likelihood that simultaneous fading will be experienced by both, therefore, becomes very small.

Frequency diversity requires the use of two or more carrier frequencies over the same path. Again, fading at one frequency, if sufficiently removed from the second frequency, is independent of fading at another, so that both frequencies are unlikely to fade simultaneously. A complete duplication of transmitters and receivers is required in frequency diversity, providing additional reliability against equipment failures* as well as against poor propagation conditions. Obviously a frequency diversity system can also serve a multi-channel system, able to transmit multiple information signals simultaneously at a level of reliability equal to a non-diversity system.

CONSIDERATIONS RELATING TO THE COMBINING OF SIGNALS BY MULTIPLEXING

1. Combining Signals

The possibility of using a well-designed microwave channel for transmitting signals other than television video has been discussed in Section III. Typical signals and their technical characteristics which might be transmitted via microwave were given in Table III. Combining these signals for transmission is accomplished by "multiplexing," a process in which the original signals are used to modulate separate "sub-carrier" frequencies, which are then mixed and used to modulate the basic carrier frequency. After initial demodulation at the receiver, the sub-carriers are separated by selective frequency filters and again demodulated to obtain the original signals. Multiplexing several types of information signals into a single microwave channel is an inexpensive method of obtaining extra communication "channels." The initial development of a network to provide the capability of handling the additional communication channels, even though not required initially, requires a nominal additional cost, and offers much in future flexibility.

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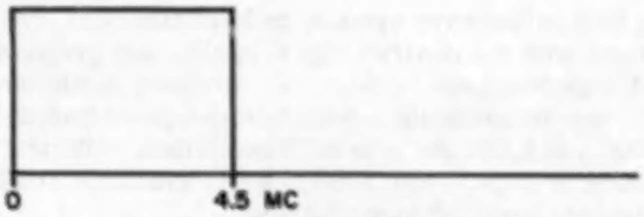
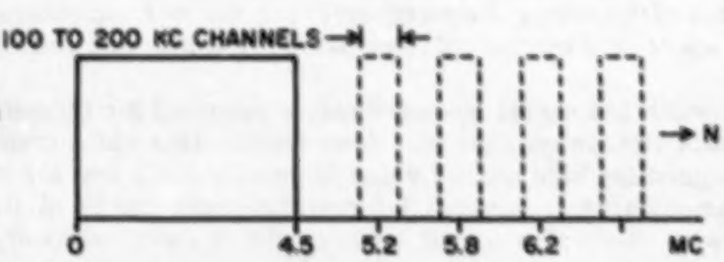
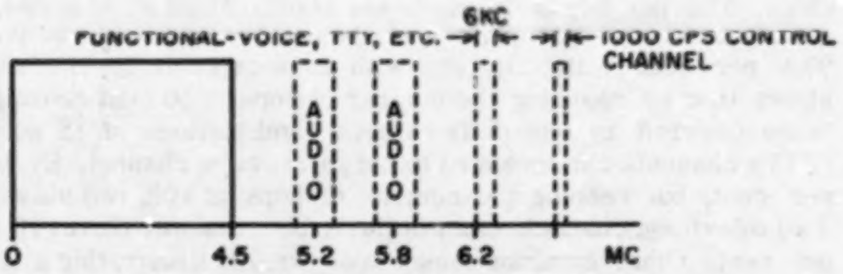
*An additional factor of equipment reliability is generally the major limitation on long haul system reliability and requires duplication of equipment at most relay sites.



BASEBAND FREQUENCY
525 LINE VIDEO ONLY



BASEBAND FREQUENCY
525 LINE VIDEO AND HIGH QUALITY FM AUDIO CHANNELS



BASEBAND FREQUENCY
MULTIFUNCTION CHANNEL

FIGURE 23
COMBINING INFORMATION IN A MICROWAVE CHANNEL

Figure 23 is a representation of the baseband of a microwave channel using several combinations of information. The video bandwidth shown may vary, depending on the quality of video to be transmitted. Consequently, the location of the sub-carriers between the subchannel is a practical filter limitation, and varies with the bandwidth of the subchannels and the available base band.

2. Effect of Noise and Bandwidth

For the normal television microwave channels used today, the subcarrier frequencies used for voice range from 5.2 to 8.5 Mc. Combining audio subchannels with a video signal always degrades the video signal-to-noise ratio below that obtainable without the audio channel providing the RF bandwidth and transmitter power remain unchanged. This occurs because part of the total transmitter RF deviation must be used by the audio channel. There is an effective split in available power between the audio and video channels. Actually, for each subcarrier the RF deviation need be only 0.1 to 1 Mc depending on placement of the subcarrier, since the high quality audio channels are themselves frequency modulated. Other problems are introduced as a result of placing the subchannels so that they neither interfere with the video channels nor are limited by the video channel. Addition of several sub-channels is possible in a system which was originally designed to use a high deviation ratio for the video channel (thereby utilizing the large RF bandwidth.)

SUMMARY OF DESIGN FACTORS

Once the basic information bandwidth or baseband has been established by determining the amount and quality of information to be transmitted, the parameters of RF bandwidth and power may be established to provide the proper reliability, linearity and noise performance.

By using FM transmission, additional RF bandwidth may be used in lieu of additional transmitter power to improve reliability and signal-to-noise ratio.

For a long haul microwave system, to be economical, it must have a minimum number of hops consistent with the desired signal quality and propagation reliability. This results in additional design margins of 10 to 40 db above minimum acceptable carrier-to-noise ratios for each hop to maintain a high percentage of immunity against fading. The power available at 2,000 and 6,000 Mc is usually more than sufficient to maintain 30 to 40 db fade margins over 30 mile hops. The 0.1 to 0.5 watts available at 12,000 Mc however, may prove to be barely adequate over the same path.

The effect of precipitation increases with frequency, and becomes significant at frequencies above about 10 kMc. Heavy rain on a single link can destroy communication completely on all following hops. In any case, the signal-to-noise ratio can be severely lowered for the duration of the rain, and consequently the use of frequencies above 10,000 Mc should be limited to short haul circuits if reasonable reliability and economy are to be maintained.

The bandwidth and signal-to-noise ratios required for transmission of voice and teletype information are always less than those required for video transmission. Consequently, a channel designed for high quality video is usually sufficient for the transmission of other types of communications. Several information types can be multiplexed and subsequently transmitted with the video signal on a single channel, with only a slight increase in RF bandwidth, a reduction in signal-to-noise ratio, and in reliability.

Table IV, discussed in Section III illustrates the sort of flexibility that can be achieved in microwave interconnection systems. A 30 Mc RF bandwidth was assumed for all examples given. The per hop path length was standardized at 30 miles. Other parameters were assumed to be adjusted such that a 4.5 Mc video signal can be transmitted over 100 hops with 99.9 per cent reliability and with an acceptable level of distortion and noise. The table shows that by reducing the number of hops to 50 (and consequently reducing the total distance covered by one-half) various combinations of 15 kc voice, 3 kc voice and teletype (TTY) channels can be added to the microwave channel. By reducing the reliability to 99.9 per cent, but keeping the number of hops at 100, two video channels can be transmitted. Two television channels can similarly be transmitted over 10 hops with a reliability of 99.9 per cent. Other combinations are shown, all illustrating a trade-off between distance, information bandwidth, signal-to-noise ratio, and reliability.

APPENDIX C

Examination of Microwave Spectrum Availability by Using Digital Computer Techniques

PURPOSE OF THE COMPUTER PROGRAM

Since the licensing of interconnection facilities must be accomplished on a shared, case-by-case basis with the Industrial and Auxiliary Broadcast Services, there is a question as to whether there is sufficient spectrum space available within the particular bands available to those services, and to educational television, to satisfy education's need for interconnection facilities.

In order to examine the degree of spectrum saturation it is necessary to investigate: (1) the regulatory provisions which apply to educational television interconnection and, (2) the existing microwave channel usage. The regulatory provisions establish the particular frequency bands available for interconnection of educational television. Data on existing microwave operations are necessary to determine the availability of actual network channels and are on file with the Commission. The volume and nature of these data are such that an assessment of spectrum availability would require much repetitious data handling.

It appeared that the best possibility for a valid determination of spectrum availability would be realized by the application of electronic digital computer techniques. Utilization of computer techniques would also allow the data to be stored in a form which would be available for repeated use. Since much of the data is of a quasi-permanent nature, it can be collected and prepared in such a way that it is useful over a long period of time if modifications are made to keep the information current.

The digital computer program was developed to provide a basis for (1) a general assessment of the microwave spectrum availability and for (2) a specific assessment of the availability of channels of different specific widths. The computer program, by providing a general spectrum assessment and specific channel identification, will also provide a basis for determining the most efficient utilization of the spectrum space actually available for a specific point-to-point network.

The use of the computer for this purpose is such that the establishment of a method for examining microwave spectrum availability is equally as important as the actual examination. Thus, while the examination to be described deals exclusively with a sample network, the method will allow an identical examination to be made for any network upon application of appropriate input data. Such an intended network could be national in scope but this report will consider only the existing assignments in one particular geographic area. This area, comprising several mid-Atlantic coastal states, was chosen because it exhibits a congested microwave traffic pattern that might be indicative of a possible future national pattern. The examination of the allocation situation in this territory should provide a test of the computer method as well as an indication of the difficulties involved in finding channels for an interconnection network. The specific sample network, is shown in Figure 19.

The computer program is written to examine the allocation situation in several steps. The first step examines the most readily available spectrum space; two further steps allow a more detailed examination and greater exercise of judgment to be made as channel availability becomes more difficult.

In the examination, space is considered to be available to the sample network if there is no co-channel operation which will interfere with the proposed operation and if the proposed operation will not interfere with an existing co-channel operation.* While the available spectrum space at a proposed network point is fundamentally defined as that range of frequencies for which interference will not occur to proposed operations, the level at which the interference might actually occur is dependent upon local requirements and can be determined by careful technical analysis.

In theory, examination of interference effects between co-channel microwave transmitters and receivers must cover three cases. These cases are based upon the directive nature of the two antenna patterns universal in application. They exist when:

CASE I
Neither antenna is pointed at the other.

CASE II
One antenna is pointed at the other, but not vice versa.

CASE III
Both antennas are pointed at each other.

The third case will, of course, be recognized as the normal situation for microwave communication, but it is the worst case for co-channel interference.

A logical examination of possible microwave interference would examine each of the three in turn for both the transmitting and receiving operations. Practically, however, this is often a difficult approach. Examination of the three cases for possible receiver interference when a proposed station is considered to be operational as a transmitter would require knowledge of the location, directivity, and frequency of the existing receiver. This information is not directly available because the FCC microwave station license cards, the primary source of input data, list the required data only according to transmitting frequencies. The receiving data can be determined, but the extended effort necessary to obtain it on a large scale for a computer input would almost defeat the purpose of using the computer to reduce repetitious data handling. Because of these factors the computer was programmed to handle the situation with existing practical limitations.

PROCEDURE OF THE COMPUTER PROGRAM

Each relay site of the sample network, labeled "Q_N" for descriptive purposes, and identified by "N" in Figure 11, is aligned sequentially and an "unassigned spectrum space" is initially identified for each site. These "unassigned spectrum spaces" are shown for explanatory purposes in Figure 24, which is a pictorial representation of the allocation situation that might exist between two adjacent sites of any proposed network. In this figure three areas of spectrum space are defined according to the degree of difficulty likely to be encountered in locating a channel for possible use in the proposed system.

Use of a frequency** from within that unassigned spectrum space which is common to both a proposed transmitting and a proposed receiving site, identified as area A in the figure, would be the optimum choice for a proposed network because that frequency could be freely used between the two points without causing interference to existing stations, and existing stations would not interfere with the proposed system. However, a frequency might not be available in metropolitan or high allocation density areas because there might not be enough channels of this description available to fulfill the proposed system channel requirements. Utilization of this frequency, or channel, would, in any case, not be in the interest of efficient spectrum usage because the usage of such a frequency would remove the associated channel from possible further use at both the proposed transmitting and receiving sites. Either of these conditions could require a further examination of the available frequency spectrum to locate the required number of network channels.

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*Co-channel operation designates the simultaneous assignment of common frequencies, which constitute a channel, to two or more independent operations.

**"Frequency" and "Channel" have parallel meanings and will be used interchangeably in this section. Both identify a microwave channel, but "Frequency" identifies such a channel by specifying the carrier frequency.

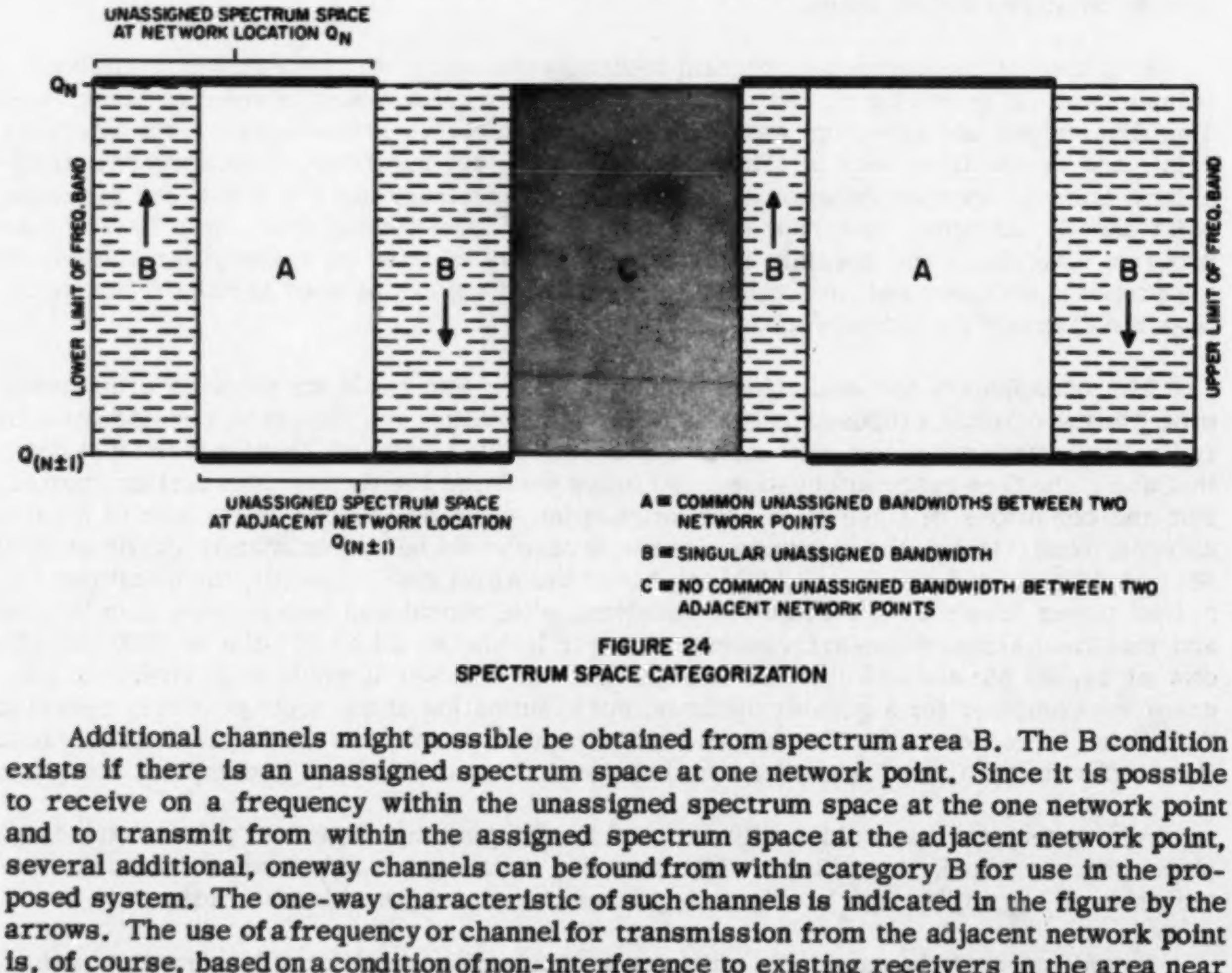
UNASSIGNED SPECTRUM SPACE AT NETWORK LOCATION Q_N
Q_N
$Q_{(N\pm1)}$
LOWER LIMIT OF FREQ. BAND
UPPER LIMIT OF FREQ. BAND
B
A
B
C
B
A
B
UNASSIGNED SPECTRUM SPACE AT ADJACENT NETWORK LOCATION $Q_{(N\pm1)}$
A = COMMON UNASSIGNED BANDWIDTHS BETWEEN TWO NETWORK POINTS
B = SINGULAR UNASSIGNED BANDWIDTH
C = NO COMMON UNASSIGNED BANDWIDTH BETWEEN TWO ADJACENT NETWORK POINTS

FIGURE 24
SPECTRUM SPACE CATEGORIZATION

Additional channels might possible be obtained from spectrum area B. The B condition exists if there is an unassigned spectrum space at one network point. Since it is possible to receive on a frequency within the unassigned spectrum space at the one network point and to transmit from within the assigned spectrum space at the adjacent network point, several additional, oneway channels can be found from within category B for use in the proposed system. The one-way characteristic of such channels is indicated in the figure by the arrows. The use of a frequency or channel for transmission from the adjacent network point is, of course, based on a condition of non-interference to existing receivers in the area near near the proposed transmitting site. Frequencies meeting this condition are identified in the second part of the computer program. It would be in the interest of efficient spectrum usage to utilize these unidirectional channels because such utilization would remove the chosen channels from possible further use only at the intended receiving site.

In spectrum area C, frequencies are assigned to other existing transmitters located within the chosen radius of both the proposed receiving and transmitting site. The directive nature of microwave networks may, however, allow certain frequencies or channels within this spectrum space to be used in the proposed network if it can be established that no interference will be sensed at the proposed receiver or caused by the proposed transmitter. The third part of the computer program was developed to correlate the directive natures of existing microwave stations with those of the proposed network to determine possible interference to the proposed receiver. The "receiving" channels identified in this manner may be correlated with the available "transmitting" spectrum space at the adjacent proposed network site to identify any additional one-way network channels. These channels may be used more efficiently, in terms of spectrum conservation, but such utilization will involve greater risk of possible interference. While utilization of a channel within spectrum area C is the least desirable alternative to a prospective user, such utilization may be necessary to provide enough channels to satisfy the network channel requirements.

The approach to providing the general spectrum assessment desired in this study required a greater computer capacity than would conceivably be necessary for the determination of channels for a singular network case. Therefore, it was decided to divide the actual program into three parts in order to keep the primary input data in card form and thereby minimize actual usage.

Step One of the computer program identifies the spectrum space that is available for transmitting or receiving at each network point on a clearly non-interfering basis. Step Two determines the spectrum space which is available for transmission from a network point, and is the first step in "fitting into" the assigned spectrum. This spectrum availability is based upon combination of the unassigned spectrum space at a network receiving point and the assigned spectrum space at a network transmitting point. Step Three of the program calculates the possible interference effects of existing transmitter stations on the proposed receiver and, in combination with Step Two, can be used to identify additional possible channels for the network.

The examination for unassigned spectrum space was made for the area within a 60-mile radius of each proposed network point. This radius was chosen by consideration of radio wave attenuation over a 60-mile distance, and on the basis of 30-mile individual hops. In Case I, the free space attenuation at 60 miles would be 138 db (for 2000 Mc) or greater. For the conditions of Case II, the net attenuation would be reduced by the gain of the one antenna. Numerically, the net attenuation in this case would be approximately 105 db at 2000 Mc and 6000 Mc, and 110 db at 12,000 Mc.* For the worst case, Case III, the maximum received power levels at the proposed receiving site, considered both antenna gain factors and maximum state-of-the-art transmitter power levels, would be -54 dbw at 6000 Mc, -71 dbw at 12,000 Mc and -62 dbw at 2000 Mc. In the latter case it would be desirable to program the computer for a greater distance, but examination of the route geometry revealed that Case III cannot exist. The 60-mile radius is thus retained in the calculations because it is sufficient for Case II situations and because it is in the interest of computer economy.

A different radius could easily be used by changing the numerical value on the computer program card. A radius of 100 miles, for instance, would provide a free-space attenuation of 142 db, but this is only 4 db greater than that of the 60-mile radius.

Examination of the geometry associated with each network point by virtue of assignment of any radius, regardless of its numerical value, can be made with the aid of Figure 25. Consider, for instance, the previously mentioned evaluation of the Case III occurrences within the unassigned spectrum space. Any frequencies or channels within the unassigned spectrum space are available as possible transmitting frequencies from the proposed relay station because no existing co-channel transmitting operations will occur within the 60-mile radius. There is a possibility, however, that a receiver might exist within the 60-mile radius whose associated transmitter is outside the radius and that the proposed transmitter might interfere with the existing receiver. Examination of such possible operations, diagrammed as X_1 and X_2 shows that Case III situations cannot exist between the proposed transmitter and an existing receiver within the 60-mile radius. Thus, free-space attenuation

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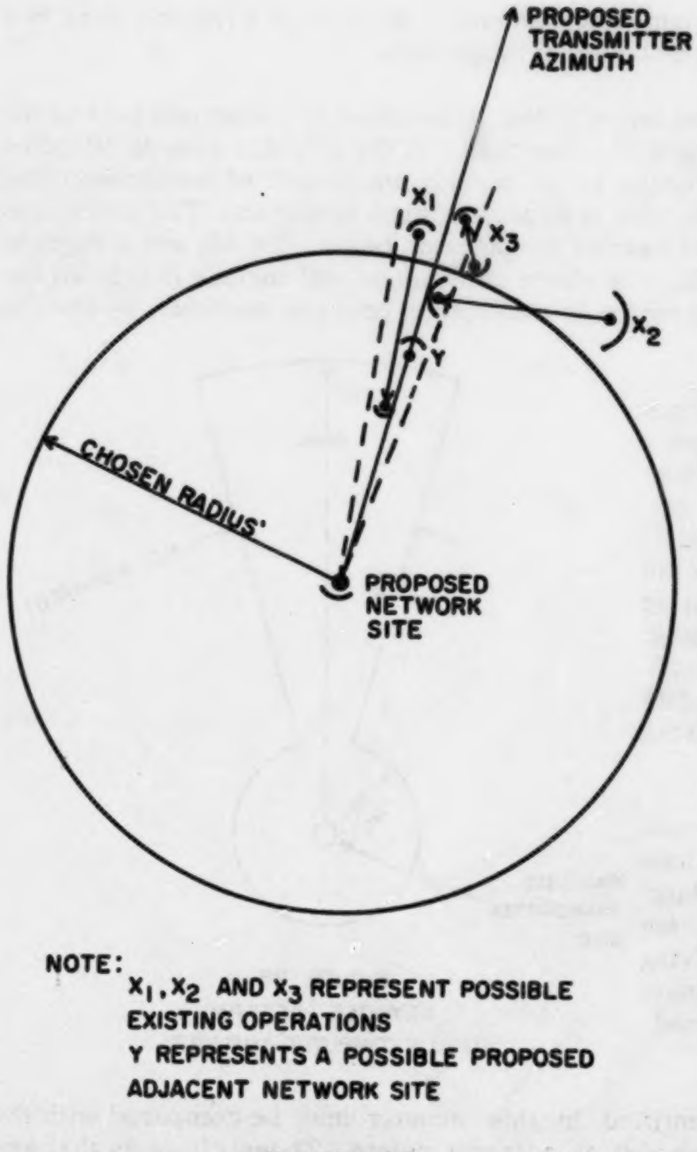
*These calculations are based on 10-foot diameter antennas at 2000 Mc and 6000 Mc and on a 1° antenna beamwidth at 12,000 Mc.



NOTE:
X_1, X_2 AND X_3 REPRESENT POSSIBLE EXISTING OPERATIONS
Y REPRESENTS A POSSIBLE PROPOSED ADJACENT NETWORK SITE

FIGURE 25
POSSIBLE MICROWAVE ANTENNA ORIENTATIONS

between the proposed transmitter and existing receiver antennas and additional attenuation due to parabolic antenna front-to-back isolation will eliminate possible interference to the existing receiver by the proposed transmitter.

More important, however, are the other conclusions that can be drawn from consideration of this figure. It has been previously established that an unassigned spectrum space at a network point means that channels within that spectrum space are available for transmitting and receiving on a non-interfering basis at that network point. Examination of the figure will show that a receiver at the proposed network site is "protected" only by the geographical distance of the chosen radius. That is, a co-channel transmitter might be located just outside the chosen radius, as is the transmitter for situation X_1. In contrast, existing receivers which are slightly outside the chosen radius and which might operate co-channel to a transmitter at the proposed network site are afforded slightly greater geographic protection since Case III cannot exist unless the transmitter associated with the receiver is closer to the proposed network transmitter than the receiver.

An unassigned spectrum space also means that it should be possible to transmit from an adjacent site to a receiver at the proposed site on a non-interfering basis to existing operations. While it would be relatively easy to further conclude that if would be possible to transmit to the proposed site from any point within the chosen radius, such is not necessarily true. If, for instance, the "adjacent" site were at Location Y in Figure 25, the proposed transmitter at Y would interfere with the existing receiver of situation X_1. Thus, to fully consider the possible use of a transmitter at Y, the possible interference to receivers in front of Y must be considered. It happens that this is the same procedure that is required to identify the available transmitting channels in spectrum area B, to be described immediately hereafter.

For the identification of possible useful frequencies from within the spectrum area identified as B in Figure 20 it is necessary to identify only the available transmitting frequencies at the proposed transmitter site, since the receiving frequencies at the proposed receiver site can be identified from the previous computer procedure. The only restriction on use of such a transmitting frequency is that it must not interfere with existing receivers. The interference possibilities of such a transmitter can be investigated by considering the receiving frequencies within a "keyhole" area, the boundaries of which are defined by the directive nature of the proposed transmitting antenna. Use of such a keyhole area is a common procedure in a microwave interference investigations.

The particular keyhole area for the investigation undertaken in the second part of the computer program is presented in Figure 26. The radius of the circular area is 30 miles and the radius of the "slot," corresponding to the main beam pattern of the transmitting antenna, is 60 miles. The arc width of the slot is dependent upon frequency. The arc values used in the program are 10 degrees for carrier frequencies below 6000 Mc and 3 degrees for carrier frequencies above 6000 Mc. The above dimensions will include nearly all the main lobe antenna patterns. The arc dimension is a computer program variable, as are the two radii.

As a conservative approximation it can be assumed that a transmitter cannot operate on any frequency for which a receiver exists within the keyhole area. This approximation corresponds to Cases II and III in the "slot" and Cases I, II and III in the "circular" area. A further approximation could be made by more refined methods, but a first approximation is felt to be sufficient, especially in view of the first difficulty encountered in obtaining receiving frequency input data.

In the actual computer program the receiving frequencies of existing operations within the network area are the input data. The permissible transmitting frequencies are identified by eliminating the receiving frequencies and their associated channel widths from the over-all available bandwidths.

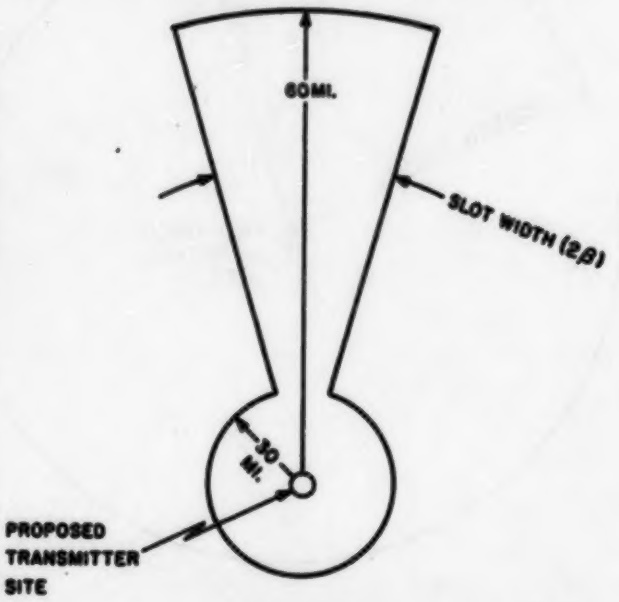


FIGURE 26
KEYHOLE PATTERN
USED IN COMPUTER ANALYSIS

The transmitting frequencies identified in this manner may be compared with the previously identified receiving frequencies at adjacent points. Those channels that are identical can be used in the proposed system, and it would be in the interest of spectrum conservation to do so.

The examination of spectrum space undertaken thus far has dealt primarily with unassigned spectrum space. It is possible that not enough channels have been identified to fulfill system requirements. This might be especially true if only one general band of frequencies (2, 6 or 12 kMc) is of interest. If neither the ideal non-interfering situation, corresponding to spectrum area B, yields the required number of channels, the proposed network must be "engineered into" the frequency environment by consideration of power, antenna directivity, terrain, and signal attenuation. In any case it is necessary that this be done by the computer program in order to complete the investigation of over-all spectrum availability undertaken in this study.

The third part of the computer program thus considers only that spectrum space corresponding to area C of Figure 11 which is that assigned to active license holders. This program identifies the existing allocation structure within 60 miles of each of the proposed network sites and tests these existing operations for possible interference to a receiver at the proposed network site. The test considers distance between stations, antenna directivity, and existing transmitter powers, in that order. Since consideration of actual terrain would

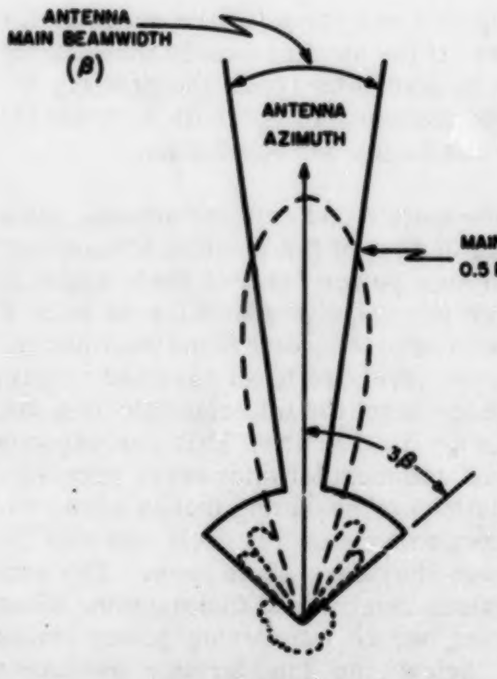

ANTENNA MAIN BEAMWIDTH
(β)
ANTENNA AZIMUTH
MAIN BEAMWIDTH 0.5 POWER POINT
3β

FIGURE 27
PARABOLIC ANTENNA PATTERN
USED IN COMPUTER ANALYSIS

be difficult to accomplish in the computer, several weighting factors are included, and the sets of frequencies available for different degrees of terrain protection are identified. The weighting factors identified for different frequencies will then require individual consideration to determine if the attenuation theorized by the weighting factor does, in fact, exist.

Referring to the flow diagram, Figure 28, the computer first identifies each of the existing operations (labeled "N" for computer purposes) within a 60-mile radius of each consecutive network point, Q_N. The relative antenna gain between the proposed and existing stations is dependent upon the relative direction of the two antennas (See Figure 29) and upon their patterns. The generalized anteanna of Figure 27 are assumed for use in the computer program. The main lobe beamwidth, β, is taken from the primary input data cards or assumed to be 5° for frequencies below 6,000 Mc and 1.5° for frequencies above 6,000 Mc. The secondary pattern, which includes the first and second sidelobe peaks of the parabolic antenna pattern is assumed to be 20 db down if the main lobe power gain of the antenna is greater than 22 db and 14 db down if the main lobe power gain is between 14 db and 22 db. The beamwidth of this side lobe pattern is assumed as ±3 β.

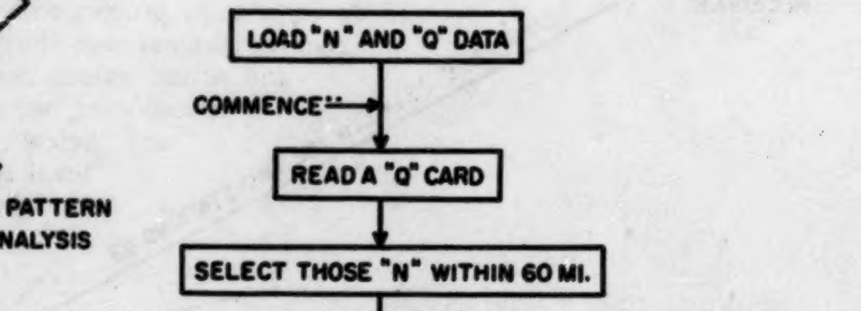

LOAD "N" AND "Q" DATA
COMMENCE
READ A "Q" CARD
SELECT THOSE "N" WITHIN 60 MI.
SELECT AN "N"
CALCULATE FREE-SPACE ATTENUATION
CALCULATE RELATIVE ANTENNA GAINS
CALCULATE RECEIVED POWER OF "N" AT "Q"
ASSIGN THE FREQUENCY OF "N" TO A SET AND PRINT RESULT
YES
ARE ALL "N" SELECTED?
NO
ARE ALL "Q" CONSIDERED?
NO
GO TO COMMENCE
YES
STOP

FIGURE 28
FLOW DIAGRAM FOR COMPUTER EXAMINATION OF
ASSIGNED SPECTRUM SPACE

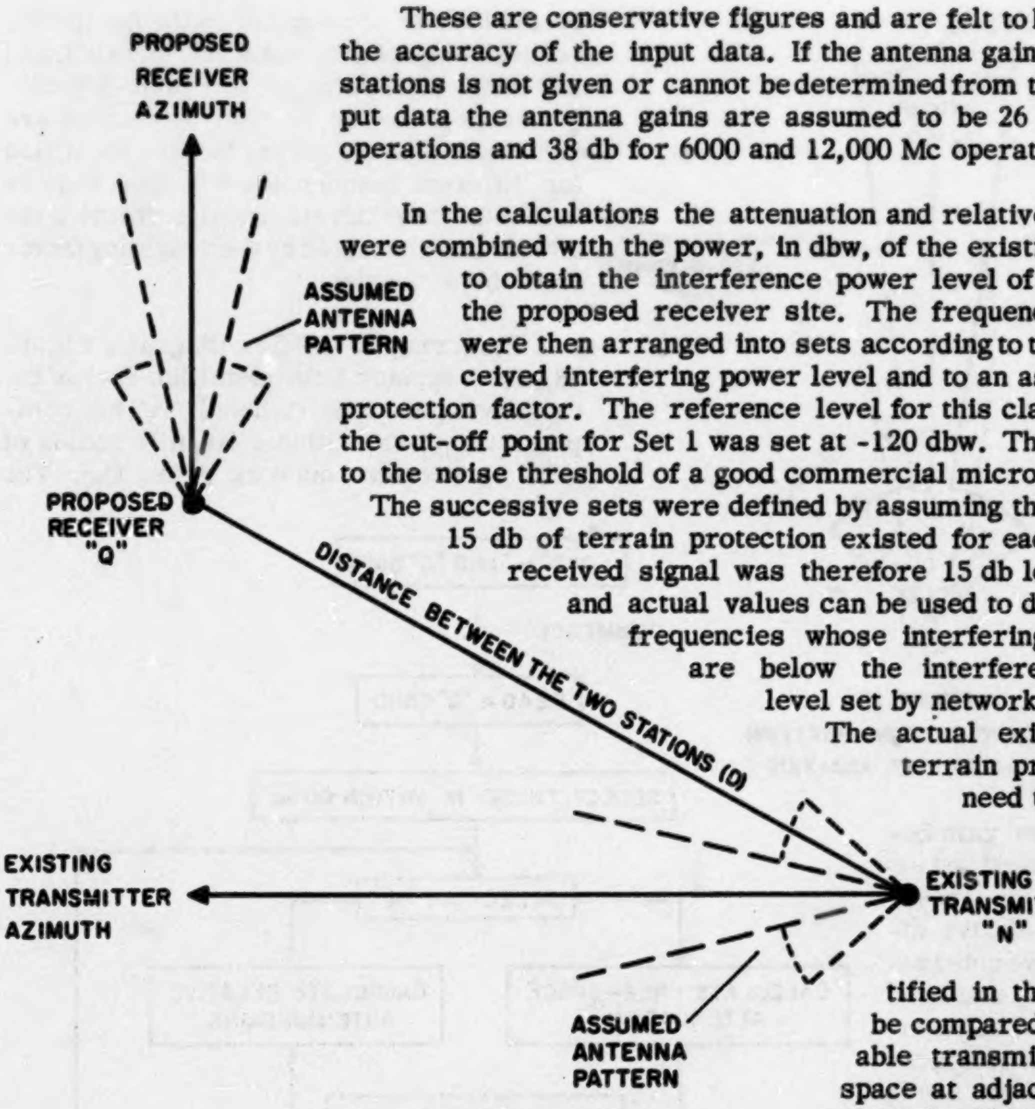


FIGURE 29
GEOMETRY FOR CONSIDERATION
OF RELATIVE ANTENNA GAINS

These are conservative figures and are felt to be adequate for the accuracy of the input data. If the antenna gain of the existing stations is not given or cannot be determined from the primary input data the antenna gains are assumed to be 26 db for 2000 Mc operations and 38 db for 6000 and 12,000 Mc operations.

In the calculations the attenuation and relative antenna gains were combined with the power, in dbw, of the existing transmitter to obtain the interference power level of the N signal at the proposed receiver site. The frequencies of each N were then arranged into sets according to the possible received interfering power level and to an assumed terrain protection factor. The reference level for this classification and the cut-off point for Set 1 was set at -120 dbw. This corresponds to the noise threshold of a good commercial microwave receiver. The successive sets were defined by assuming that an additional 15 db of terrain protection existed for each, and that the received signal was therefore 15 db lower. The sets and actual values can be used to determine those frequencies whose interfering power levels are below the interference avoidance level set by network requirements. The actual existence of such terrain protection would need to be checked by a map study. The receiving frequencies identified in this manner can be compared with the available transmitting spectrum space at adjacent network points for identification of additional possible channels for the proposed system.

An identical procedure could be followed to determine the possible interference caused by a transmitter at Q_N by investigating each N for each of the identified receiving frequencies. Possible transmitter interference can easily be investigated by another method since the transmitter interference investigation program (Part 2) considered all spectrum space within the available bands.

ASSESSMENT OF SPECTRUM AVAILABILITY — USING THE COMPUTER RESULTS

As the computer program results are the basis for an assessment of the spectrum availability, they can be used in a number of ways. It is possible, for instance, to utilize the results to provide a categorical spectrum availability assessment for the three different degrees of channel location difficulty and for the three spectrum areas (2000, 6000, and 12,000 Mc) available for interconnection of educational television facilities. Such a categorical assessment is useful in considering efficiency of spectrum utilization but is limited in providing an overall assessment in that channels which might be available if combinations of the three spectrum areas could be used are not identified.

For instance, if there were an A category spectrum space of 18 Mc width it would be possible to get only one 10 Mc or one 15 Mc channel for use in the network. On the other hand, if there were an adjacent B space of 4 Mc width it would be possible to use the whole 22 Mc width as a B space. Subsequently, one 20 Mc or two 10 Mc channels could be identified as being available for the network. The factor of greatest importance is that with this method of examination it is possible to examine the total spectrum availability, regardless of category.

The total availability situation can be seen most clearly if the computer program results are diagrammed as in Figure 30. In this figure, the coded lines represent the spectrum areas within which it is possible to receive at each network point on a non-interfering basis. The spectrum spaced represented as "usable assigned frequencies" is that for which no co-channel interference should be caused to a proposed receiver by existing operations because the level of any such possible interfering signals will be below a chosen threshold. The threshold level is determined by the interference avoidance requirements of each specific network and is thus not always the same numerical figure. The level that is often chosen is the noise threshold level of the intended network receivers because received signals whose amplitude is below this level will not be identified by the receiver. The value -120 dbw was chosen for the particular evaluation described in Figure 30 because this is the noise threshold level of a good microwave receiver. Other levels could be set by particular network requirements or less strict interference avoidance criteria.

The network points in Figure 26 are identified by the "Q" number on the right ordinate. The numbers correspond to the network locations identified in Figure 11 and the "Q" is part of the label used to identify proposed network relay sites for the computer program. In Figure 31 another set of lines is plotted to represent the spectrum area which was identified by Part II of the computer program as being available for transmitting on a non-interfering basis with existing receivers. This particular example is unusual in that the entire band is available for transmitting at every network point.

If these two figures are combined, as in Figure 32, channels of a chosen width can be identified and a spectrum availability evaluation can be made. The two necessary conditions for identification of these channels are; (1) a spectrum space of the desired channel width must be available for transmission from an adjacent network point and (2) a corresponding space must be available for receiving at a chosen network point. The number of channels that meet these conditions were evaluated for several bands and the results are presented in Figures 12 and 13.

The graphic technique followed in Figures 30, 31, and 32 is extremely valuable and is recommended for the reduction to an obvious "picture" of the abstract relations involved in examining the over-all spectrum availability for a number of points. This technique also permits the exact location of frequencies and channels available for use in a system and will be used later in this report in making such locations for a typical microwave network.

Figures 12 and 13 summarize the data obtained from application of the graphic technique of Figures 30, 31, and 32 to the five general spectrum areas considered in the computer program. These two figures represent the over-all spectrum availability for the chosen typical network. Note that these figures present an evaluation for only one direction of transmission. While both directions of communication were considered and evaluated, there were only minor differences in over-all spectrum availability due to direction of network transmission.

Figures 12 and 13 express the relative trends expected and noted earlier when the maps of existing operations were considered. The spectrum availability can be seen to increase with the frequency (2,000, 6,000, or 12,000 Mc) of the band of possible operations and also

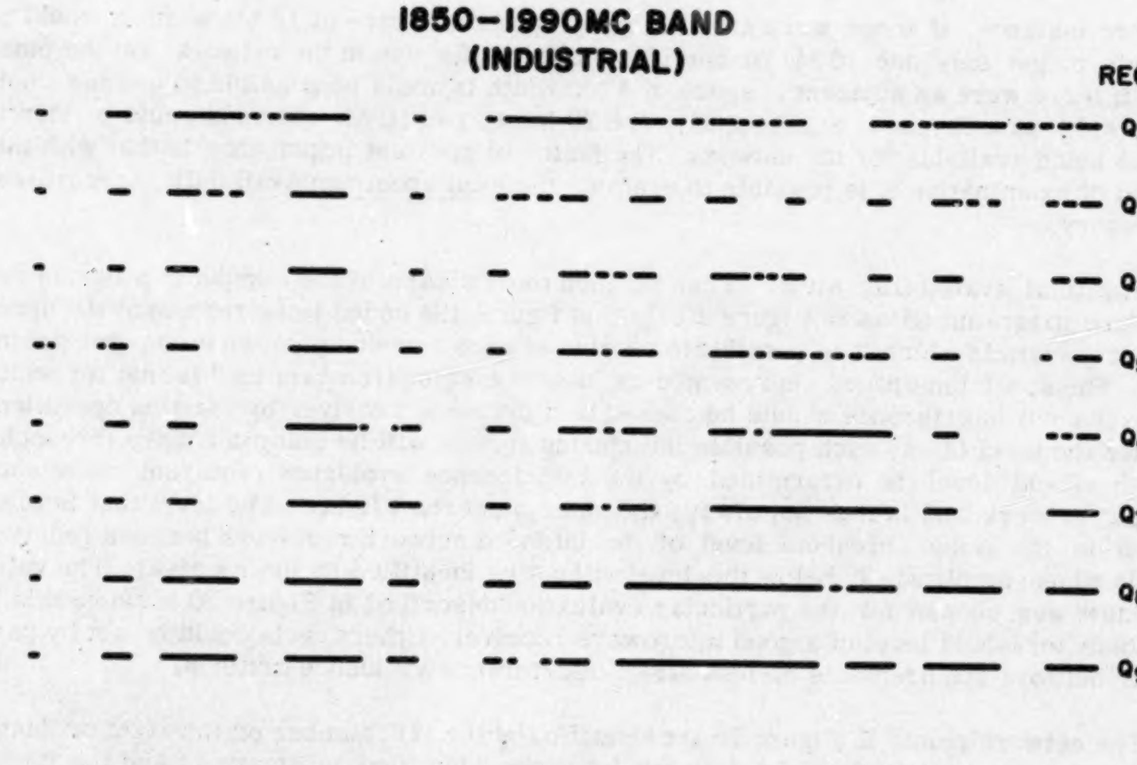


FIGURE 30

GRAPHIC PRESENTATION OF

USABLE NETWORK RECEIVE FREQUENCIES

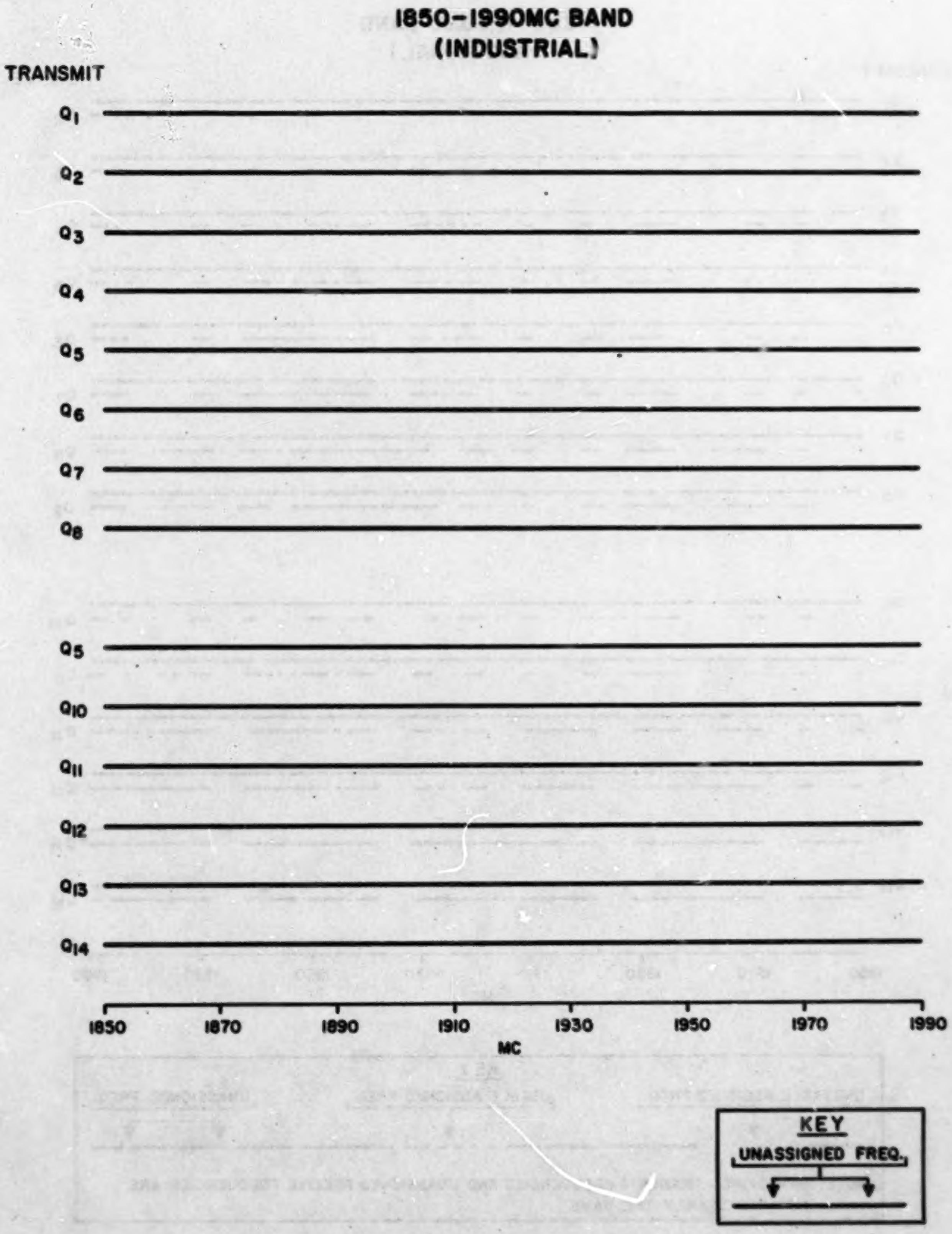


FIGURE 31
GRAPHIC PRESENTATION OF
USABLE NETWORK TRANSMIT FREQUENCIES

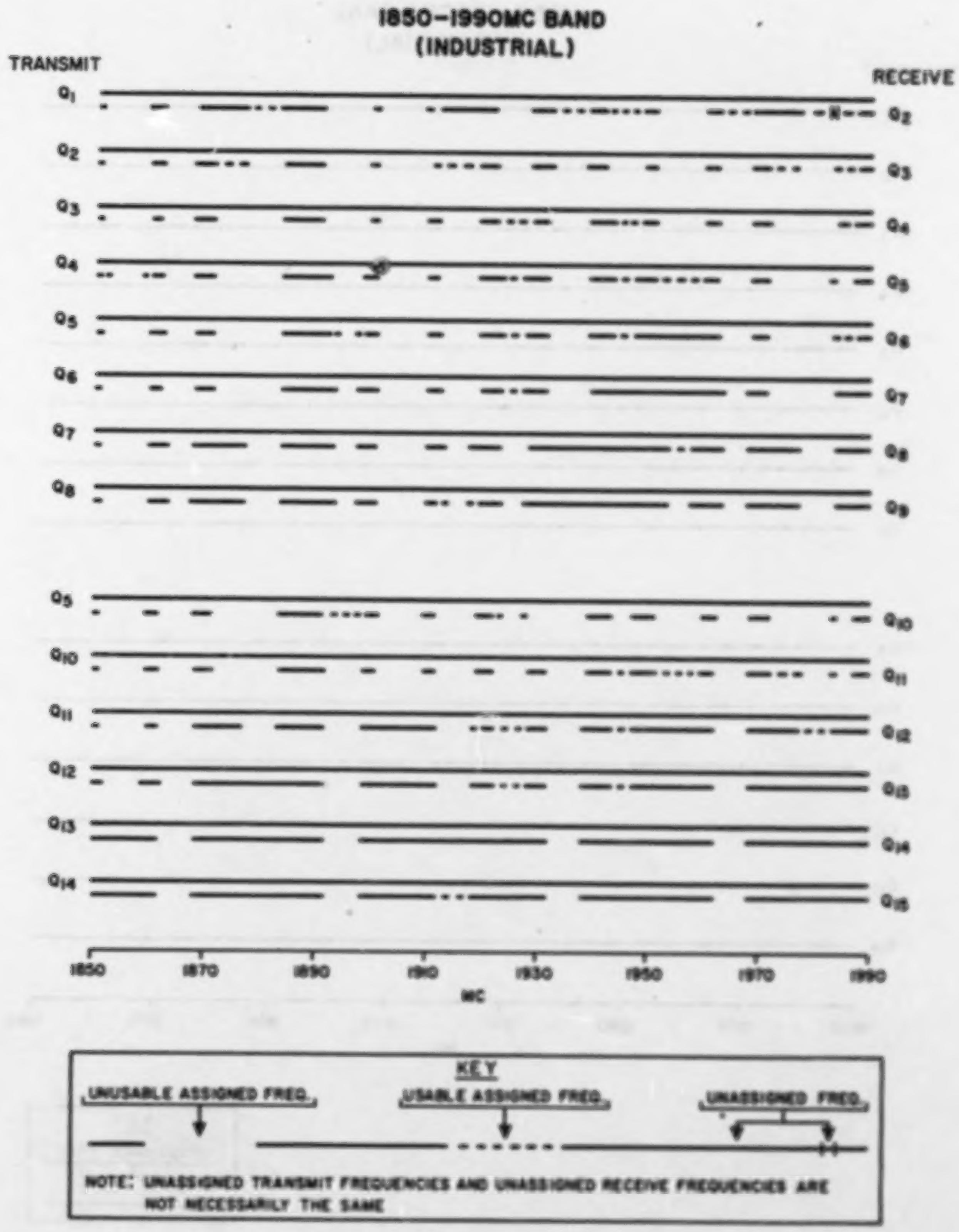


FIGURE 32
GRAPHIC PRESENTATION OF
USABLE NETWORK FREQUENCIES

as the network sites are placed farther from metropolitan areas. The real importance of these figures, however, is that the degree of availability is expressed as an exact number of channels of a given width. Examination of the 6,575-6,875 Mc band in Figure 12 for instance, shows that a minimum of seventeen 10 Mc channels, six 20 Mc channels, and five 30 Mc channels are available at any network point. Of the total possible channels, these are 34 per cent, 24 per cent, and 31 per cent respectively. In contrast, no channels of any width are available in the 1850-1990 Mc band between network points 2 and 3. In the 12,200-12,700 Mc band there is a 64 per cent, 60 per cent, and 56 per cent availability of channels for 10 Mc, 20 Mc, and 30 Mc channels respectively.

The evaluation for the Auxiliary Broadcast bands (Figure 13) is of particular interest because it presents a seeming paradox to the general trends noted for normal spectrum utilization. The exceptions are due to several operational and regulatory factors as well as a minor limitation placed upon the computer program by indefinite primary file input data. The inconsistencey with actual conditions occurs because there are several licensees authorized to operate mobile units in or near "New York and New Jersey," "USA," "Pennsylvania and Delaware," or the "Northeastern United States." Data for these operations could not be considered in the computer program because latitude and longitude could not be calculated precisely. Since there are relatively few of these operations, they can be considered on a case-by-case basis.

Another departure from general trends in that the 6,000 Mc band is totally assigned while there are numerous channels yet available in the 2,000 Mc Television Auxiliary Broadcast band. This condition is the result of several operational and regulatory limitations on 2000 Mc operations. For instance, the mobility of 6,000 Mc equipment is greater in that smaller antennas can be used in the higher frequency band for a given amount of antenna gain. Equipment available for the 6,000 Mc band is also newer and of generally better quality. The Rules and Regulations of the FCC also affect this reversal of the normal trend because 25 Mc channels are provided for 6,000 Mc band operations while 17 Mc channels are provided for 2,000 Mc band operations. The wider channels are more desirable to broadcasters because signal quality can be maintained at a higher level and because subcarriers can be added into the channel with less difficulty. All of these factors combine to make channels in the 6,000 Mc band more desirable and therefore, more scarce.

It should be noted that while the evaluation of this report considered 10, 20, and 30 Mc channels for comparative purposes, the actual channel availability is somewhat different because Auxiliary Broadcast Rules and Regulations provide 17 Mc channels in the 2,000 Mc band and 25 Mc channels in the 6,000 Mc band. If the user's sole concern is with Broadcast Interconnection channels, an evaluation can be made for the appropriate channel widths.

This application of digital computer techniques has identified the relative degree of spectrum availability in terms of exact figures for a number of channels of selected widths. The computer investigation is valuable beyond the actual results in that a technique of spectrum evaluation is established which can be used for expanding the sample examination considered herein for any particular set of requirements. The technique is applied herein to a particular situation or an exemplary network, but it can be applied to other similar situations. The particular assessment made herein has been made for an area with congested microwave traffic patterns and, as such, should be valid for future allocation situations as present lightly allocated areas become more frequency crowded. The generality of the approach also allows identification of the actual placement of available channels.

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APPENDIX D

Maps

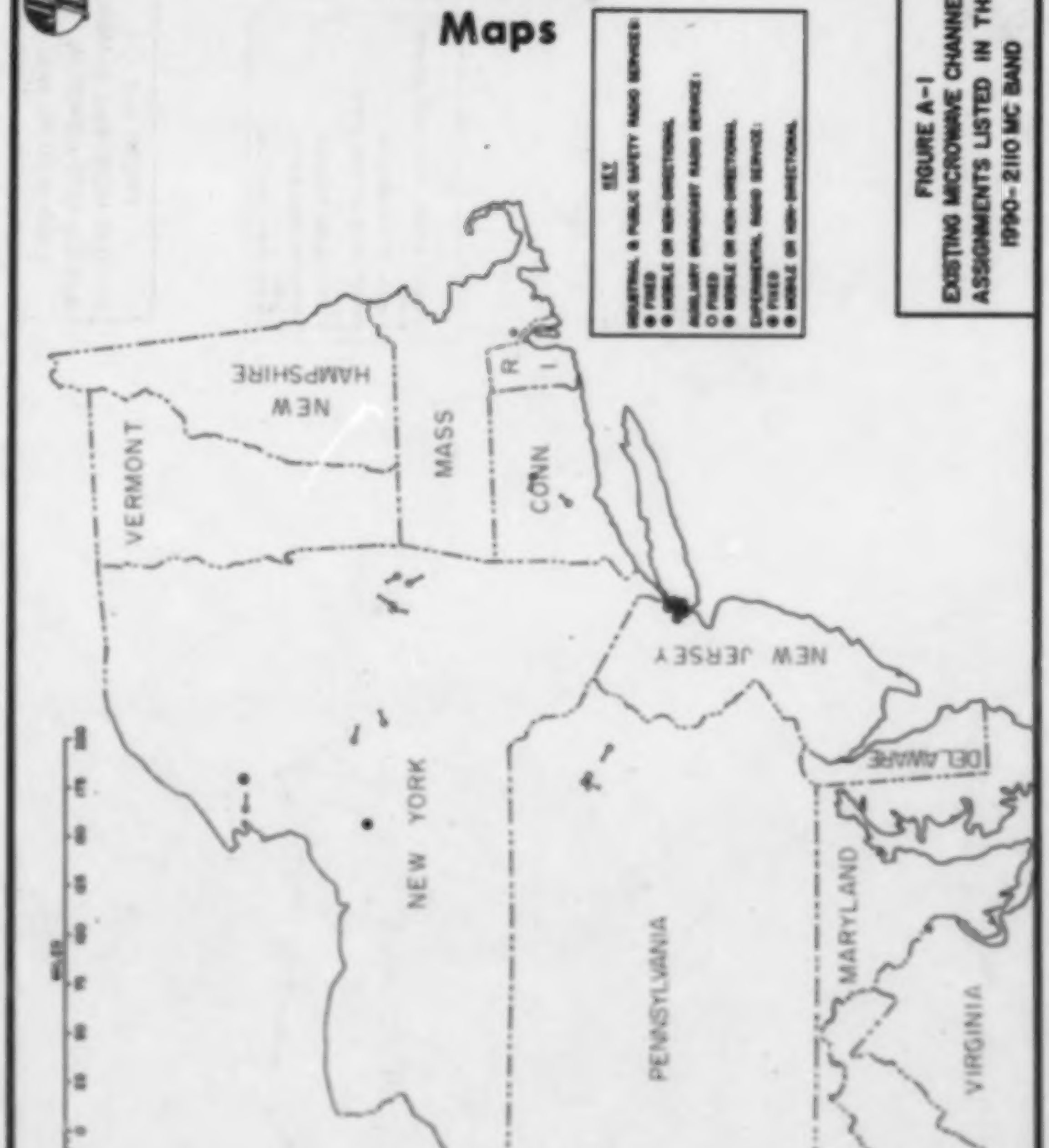
KEY
INDUSTRIAL & PUBLIC SAFETY RADIO SERVICES:
● FIXED
● MOBILE OR NON-DIRECTIONAL
AUXILIARY BROADCAST RADIO SERVICE:
○ FIXED
● MOBILE OR NON-DIRECTIONAL
EXPERIMENTAL RADIO SERVICE:
● FIXED
● MOBILE OR NON-DIRECTIONAL
NEW HAMPSHIRE
VERMONT
MASS
R I
CONN
NEW YORK
NEW JERSEY
PENNSYLVANIA
DELAWARE
MARYLAND
VIRGINIA
WEST VIRGINIA
OHIO
MILES

FIGURE A-1
EXISTING MICROWAVE CHANNEL
ASSIGNMENTS LISTED IN THE
1990-2110 MC BAND

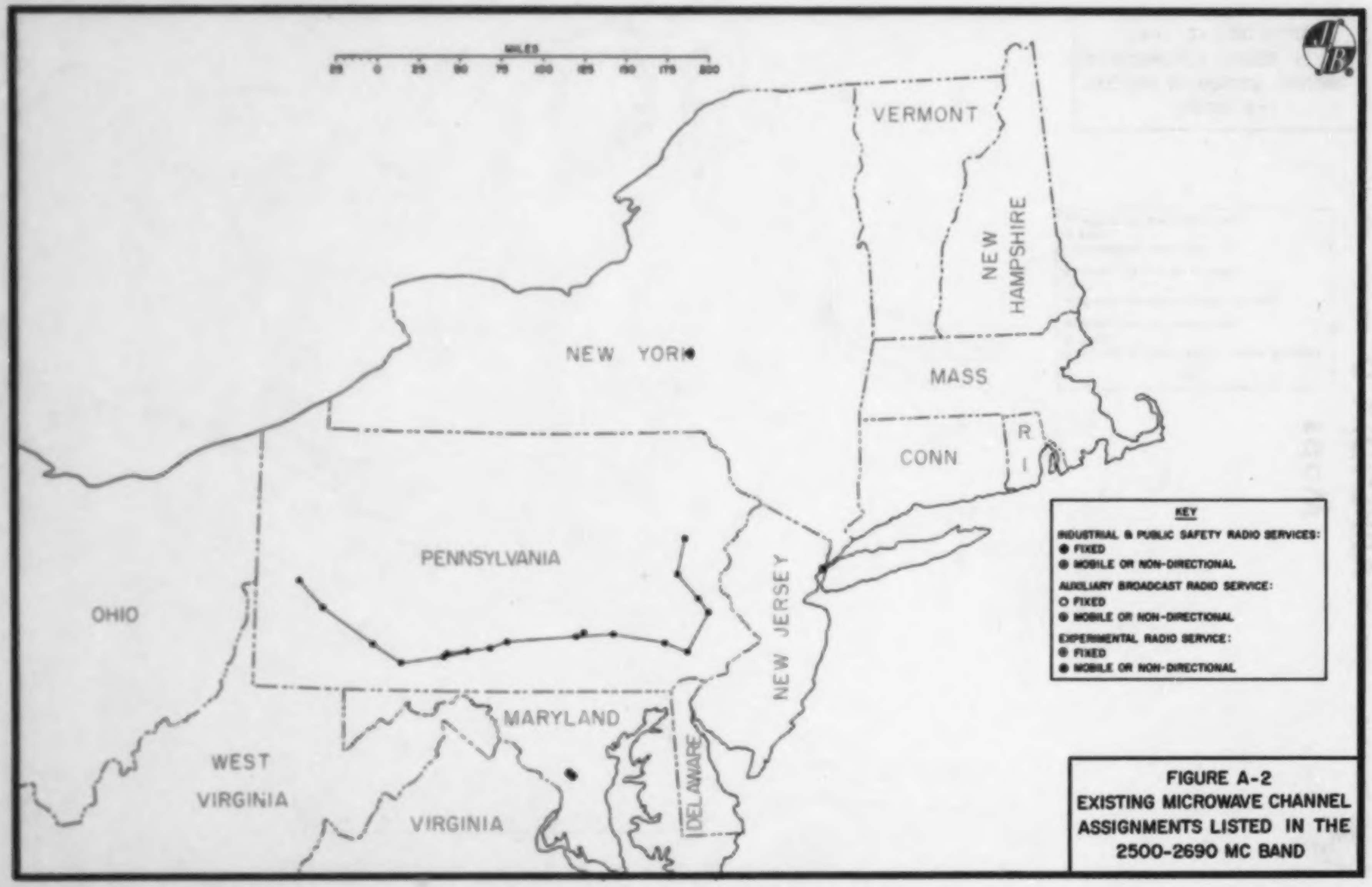
MILES
25 0 25 50 75 100 125 150 175 200
VERMONT
NEW HAMPSHIRE
NEW YORK
MASS
CONN
R I
PENNSYLVANIA
NEW JERSEY
OHIO
WEST VIRGINIA
MARYLAND
DELAWARE
VIRGINIA
KEY
INDUSTRIAL & PUBLIC SAFETY RADIO SERVICES:
● FIXED
● MOBILE OR NON-DIRECTIONAL
AUXILIARY BROADCAST RADIO SERVICE:
○ FIXED
● MOBILE OR NON-DIRECTIONAL
EXPERIMENTAL RADIO SERVICE:
● FIXED
● MOBILE OR NON-DIRECTIONAL

FIGURE A-2
EXISTING MICROWAVE CHANNEL ASSIGNMENTS LISTED IN THE 2500-2690 MC BAND

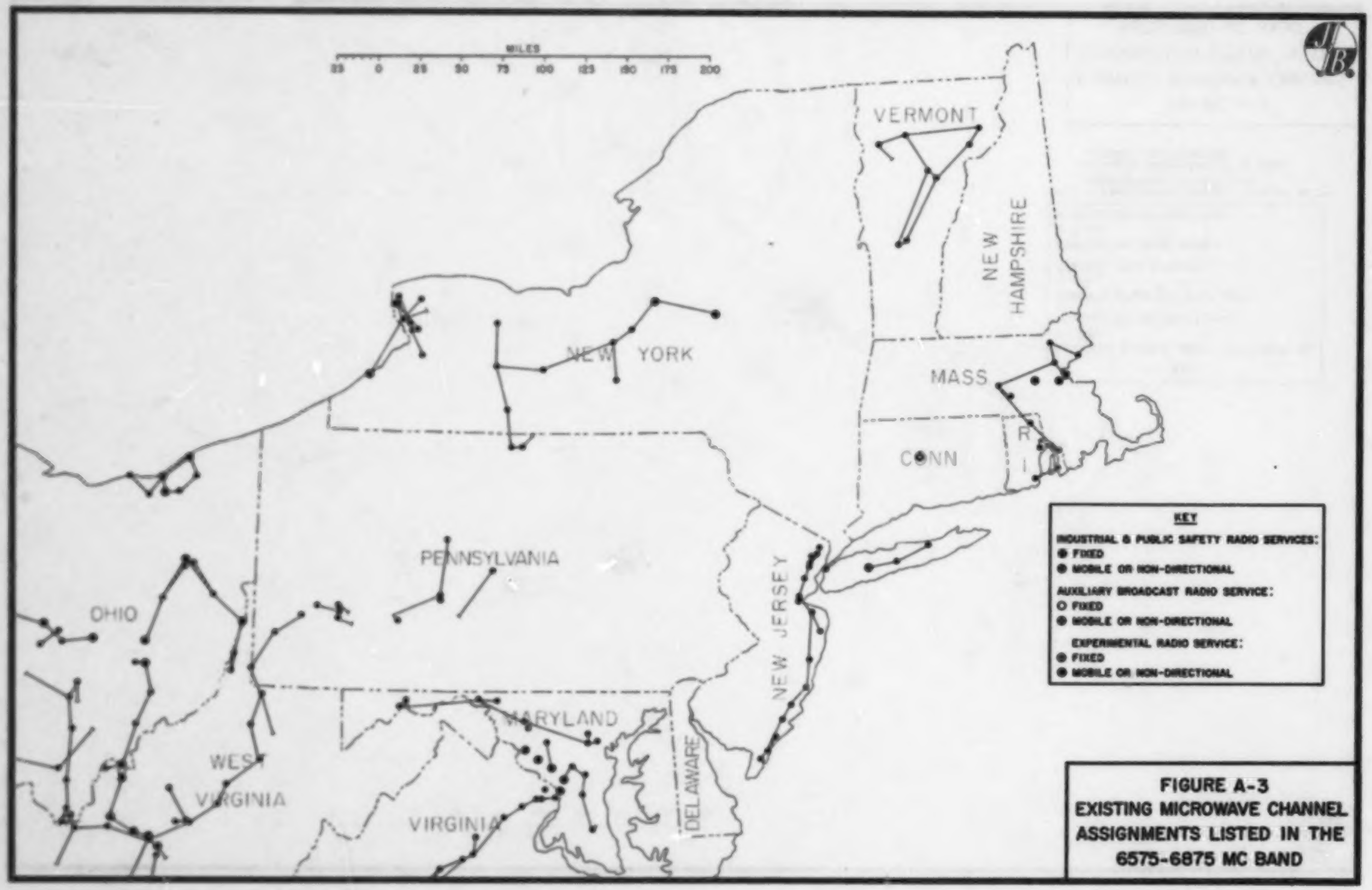
MILES
25
0
25
50
75
100
125
150
175
200
VERMONT
NEW HAMPSHIRE
MASS
CONN
R
I
NEW YORK
PENNSYLVANIA
NEW JERSEY
OHIO
WEST VIRGINIA
MARYLAND
DELAWARE
VIRGINIA
KEY
INDUSTRIAL & PUBLIC SAFETY RADIO SERVICES:
● FIXED
● MOBILE OR NON-DIRECTIONAL
AUXILIARY BROADCAST RADIO SERVICE:
○ FIXED
● MOBILE OR NON-DIRECTIONAL
EXPERIMENTAL RADIO SERVICE:
● FIXED
● MOBILE OR NON-DIRECTIONAL

FIGURE A-3
EXISTING MICROWAVE CHANNEL
ASSIGNMENTS LISTED IN THE
6575-6875 MC BAND

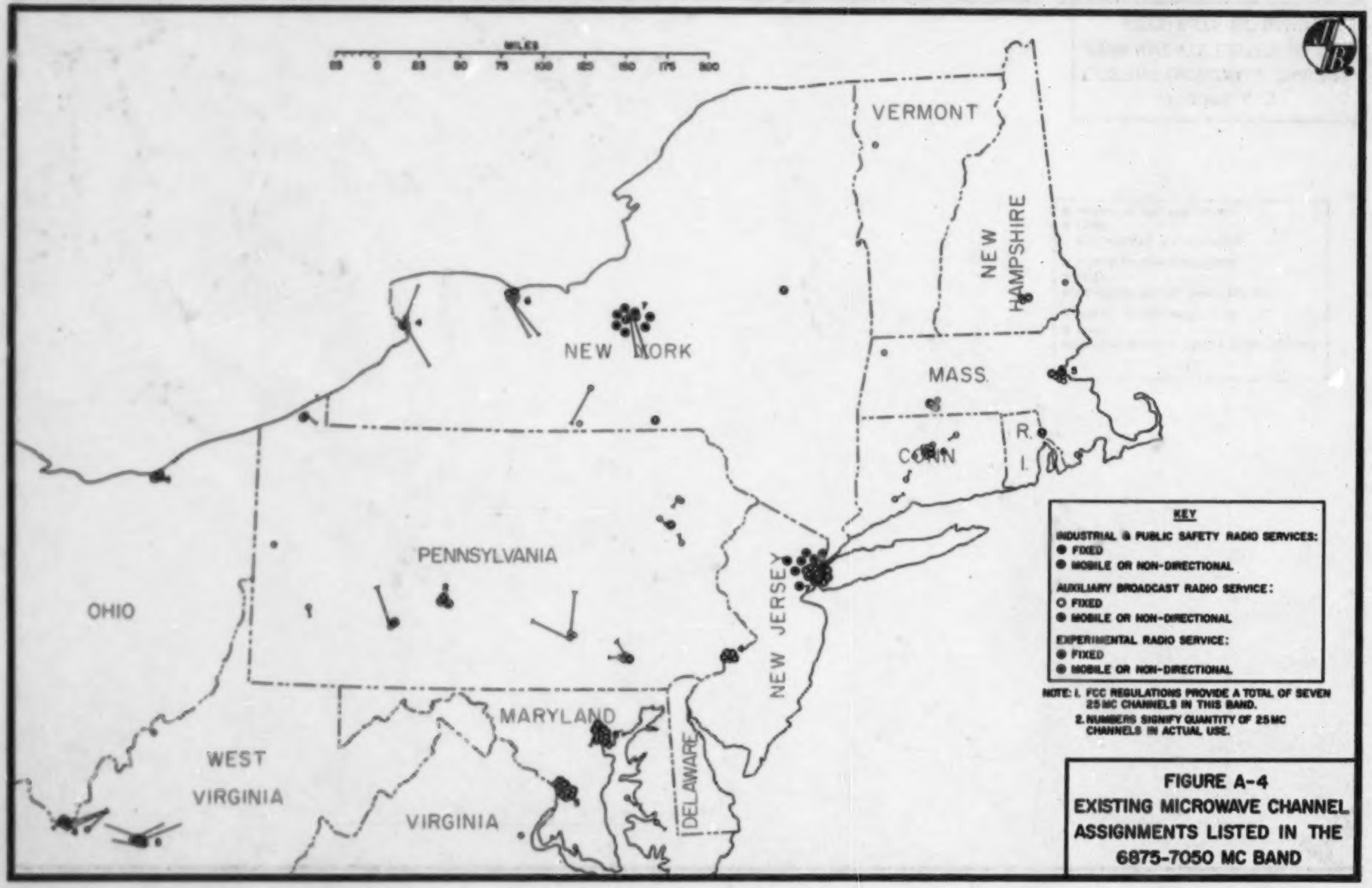
MILES
25 0 25 50 75 100 125 150 175 200
VERMONT
NEW HAMPSHIRE
MASS.
R. I.
CONN
NEW YORK
PENNSYLVANIA
NEW JERSEY
OHIO
WEST VIRGINIA
VIRGINIA
MARYLAND
DELAWARE
KEY
INDUSTRIAL & PUBLIC SAFETY RADIO SERVICES:
● FIXED
● MOBILE OR NON-DIRECTIONAL
AUXILIARY BROADCAST RADIO SERVICE:
○ FIXED
● MOBILE OR NON-DIRECTIONAL
EXPERIMENTAL RADIO SERVICE:
● FIXED
● MOBILE OR NON-DIRECTIONAL
NOTE: 1. FCC REGULATIONS PROVIDE A TOTAL OF SEVEN 25 MC CHANNELS IN THIS BAND.
2. NUMBERS SIGNIFY QUANTITY OF 25 MC CHANNELS IN ACTUAL USE.

FIGURE A-4
EXISTING MICROWAVE CHANNEL ASSIGNMENTS LISTED IN THE 6875-7050 MC BAND

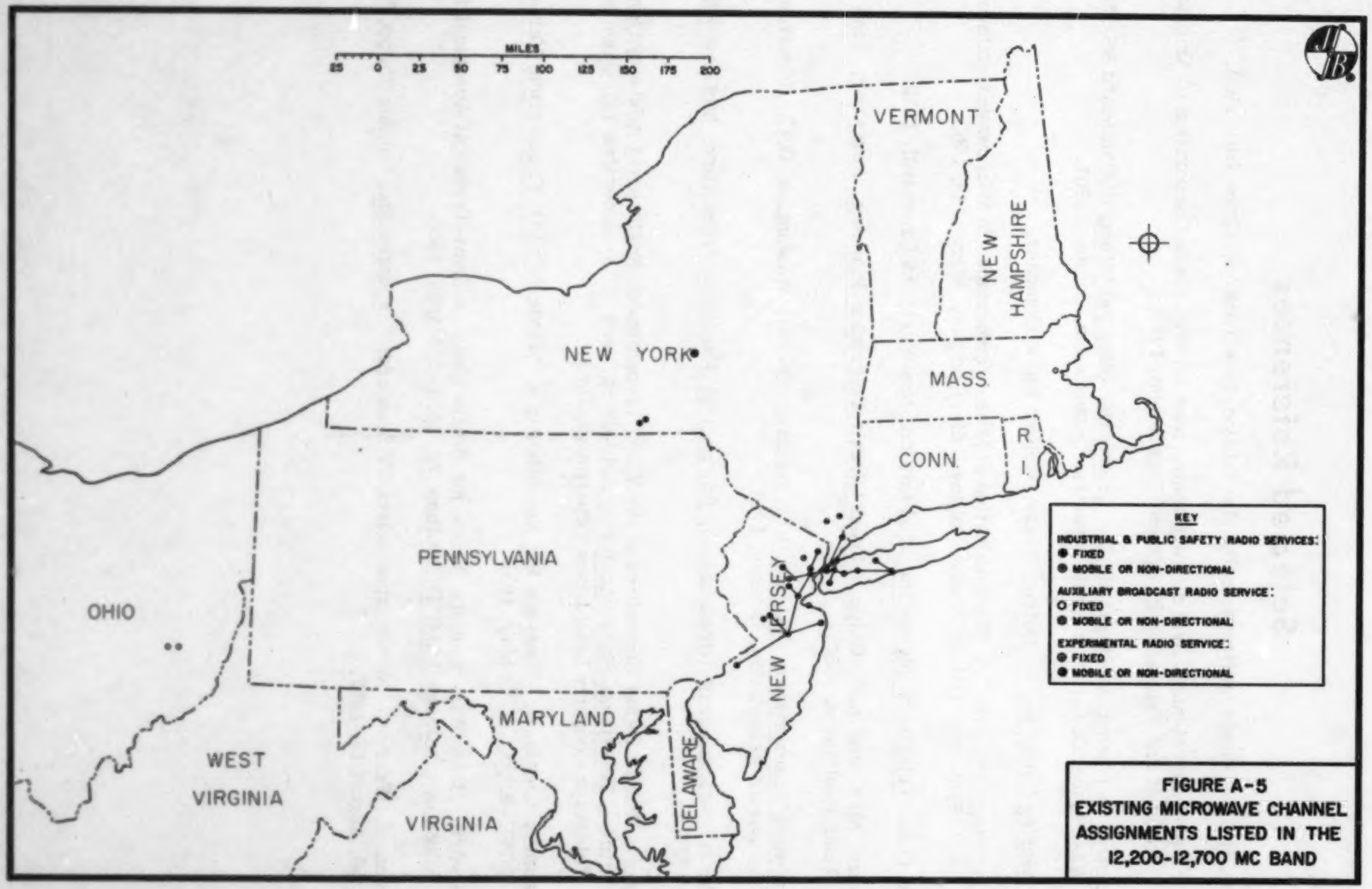
MILES
25 0 25 50 75 100 125 150 175 200
VERMONT
NEW HAMPSHIRE
MASS.
CONN.
R. I.
NEW YORK
PENNSYLVANIA
NEW JERSEY
OHIO
WEST VIRGINIA
MARYLAND
DELAWARE
VIRGINIA
KEY
INDUSTRIAL & PUBLIC SAFETY RADIO SERVICES:
● FIXED
● MOBILE OR NON-DIRECTIONAL
AUXILIARY BROADCAST RADIO SERVICE:
○ FIXED
● MOBILE OR NON-DIRECTIONAL
EXPERIMENTAL RADIO SERVICE:
● FIXED
● MOBILE OR NON-DIRECTIONAL

FIGURE A-5
EXISTING MICROWAVE CHANNEL ASSIGNMENTS LISTED IN THE 12,200-12,700 MC BAND

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